VOLUME, SPECIFIC GRAVITY & LATEWOOD OF PONDEROSA PINE AS A RESPONSE TO SELECTED THINNING, MORPHOLOGICAL AND ENVIRONMENTAL FACTORS

LEE THOMAS ALFORD

VOLUME, SPECIFIC GRAVITY AND LATEWOOD OF PONDEROSA PINE AS A RESPONSE TO SELECTED THINNING, MORPHOLOGICAL AND ENVIRONMENTAL FACTORS

An Abstract of a Thesis
Presented to the Graduate Faculty
Northern Arizona University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Forestry

---

by
Lee Thomas Alford

August 1970

LIBRARY COPY
ROCKY MT. FOREST & RANGE
EXPERIMENT STATION

During September and October of 1962 thinning plots were established at the Taylor Woods unit of the Fort Valley Experimental Forest. Eighteen plots were thinned to six different basal area levels ranging from 30 to 150 square feet and three were left as control plots. Six trees from each of the 30, 80 and 150 basal area levels plus six trees from the unthinned plots were sampled in 1969 at five foot intervals up the bole. The six years after thinning were then compared with the six years before thinning to determine the effect of thinning on growth and specific gravity.

1. Thinning:
    a. Increased radial growth rate, with an increase in growth with decreasing basal area per acre.
    b. Increased volume growth per tree, with approximately the same volume growth per acre found in the higher residual basal areas while the 30 basal area level showed a decrease in volume growth per acre. This indicated that the 30 level was not fully utilizing the site.
    c. Did not significantly affect specific gravity.
    d. Did not significantly affect per cent latewood.
    e. Increased tree taper.
2. Specific gravity:
    a. Decreased with increasing crown size.

b. Decreased with increasing height in the tree.

c. Decreased with decreasing basal area per acre.

d. Decreased with decreasing per cent latewood.

e. Had no consistent relationship to latewood width, ring width or rings per inch.

f. Was predicted better by external tree characteristics (height in the tree, basal area per acre, diameter breast high, total tree height and per cent live crown) than internal characteristics.

VOLUME, SPECIFIC GRAVITY AND LATEWOOD OF PONDEROSA PINE AS A RESPONSE TO SELECTED THINNING, MORPHOLOGICAL AND ENVIRONMENTAL FACTORS

A Thesis

Presented to the Graduate Faculty

Northern Arizona University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Forestry

---

by

Lee Thomas Alford

August 1970

ACKNOWLEDGMENTS

The author is most deeply indebted to Mr. Glenn Voorhies, whose interest, encouragement, advice, guidance, and assistance throughout my graduate program made this thesis possible.

Appreciation is extended to Dr. E. A. Kurmes for his interest and encouragement during the duration of this study.

Special appreciation is given to the School of Forestry and the Rocky Mountain Forest and Range Experiment Station for financing this study.

Special appreciation is also extended to my wife for her encouragement and understanding and to her parents and mine for their support and encouragement throughout my college career.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	THE PROBLEM, OBJECTIVES AND SCOPE OF THE STUDY	1
	Statement of Problem and Objectives	2
	Problem	2
	Objectives	3
	Scope of the Study	3
II.	REVIEW OF THE LITERATURE	4
III.	EXPERIMENTAL DESIGN AND PROCEDURES	15
	Procedures	15
	Thinning plots	15
	Trees	15
	Field data	16
	Tree processing	16
	Laboratory processing	17
	Analysis of Results	19
IV.	EXPERIMENTAL RESULTS	22
	Volume Growth	23
	Accumulated volume	23
	Annual volume	32
	Annual volume growth--per cent of the twelve year volume	39
	Earlywood and latewood volume	40

CHAPTER PAGE

Per cent latewood volume 50

Per cent latewood volume--annual volume relationship 52

Volume growth summary 52

Specific Gravity 58

Correlations between specific gravity and tree characteristics 61

Specific gravity summary 78

Radial Growth 79

Annual radial increment 79

Width of the six ring segments 87

Annual increment as related to selected external and environmental factors 90

Radial growth summary 95

V. DISCUSSION AND SUMMARY 96

VI. RECOMMENDATIONS FOR FURTHER RESEARCH 101

BIBLIOGRAPHY 102

APPENDIX 108

LIST OF TABLES

TABLE PAGE

I. Statistical Comparison between Rings 7-12 and 1-6 of Accumulated Volume by Heights of Different Treatment Levels 30

II. Statistical Comparison Between Rings 7-12 and 1-6 of Annual Volume by Heights of Different Treatment Levels 38

III. Comparison Between Rings 7-12 and 1-6 of Annual Volume Growth--Per Cent of 12 Year Volume by Heights of Different Treatment Levels 41

IV. Statistical Comparison Between Rings 7-12 and 1-6 of Per Cent Latewood Volume by Heights of Different Treatment Levels 47

V. Statistical Comparison Between Rings 7-12 and 1-6 of Earlywood Volume of Different Treatment Levels 48

VI. Statistical Comparison Between Rings 7-12 and 1-6 of Latewood Volume of Different Treatment Levels 49

VII. Statistical Comparison Between Rings 7-12 and 1-6 of Specific Gravity of Different Thinning Levels 59

TABLE PAGE

VIII. Simple Linear Regression Equations and Best Multiple Regression Equations for Estimating Specific Gravity After Extraction During the 6 Years Before Thinning of Ponderosa Pine 75

IX. Simple Linear Regression Equations and Best Multiple Regression Equations for Estimating Specific Gravity After Extraction During the 6 Years After Thinning from External Tree Characteristics of Ponderosa Pine 76

X. Simple Linear Regression Equations and Best Multiple Regression Equations for Estimating Specific Gravity After Extraction During the 6 Years after Thinning from External and Internal Tree Characteristics of Ponderosa Pine 77

XI. Statistical Comparison Between Rings 7-12 and 1-6 of Annual Radial Increment by Heights of Different Treatment Levels . . . 86

XII. Simple Linear Regression Equations and Best Multiple Regression Equations for Estimating Annual Increment after Thinning from External Tree Characteristics 94

LIST OF FIGURES

FIGURE		PAGE
1.	Accumulated Volume Growth of Unthinned Ponderosa Pine During Two Time Periods	24
2.	Accumulated Volume Growth of Ponderosa Pine Before and After Thinning to 150 Basal Area Level	25
3.	Accumulated Volume Growth of Ponderosa Pine Before and After Thinning to 80 Basal Area Level	26
4.	Accumulated Volume Growth of Ponderosa Pine Before and After Thinning to 30 Basal Area Level	27
5.	Accumulated Volume Growth of Ponderosa Pine--Comparison of Four Levels of Thinning, Before and After Thinning all Bolts	28
6.	Annual Volume Growth of Unthinned Ponderosa Pine During Two Time Periods	33
7.	Annual Volume Growth of Ponderosa Pine Before and After Thinning to 150 Basal Area Level	34
8.	Annual Volume Growth of Ponderosa Pine Before and After Thinning to 80 Basal Area Level . .	35

FIGURE PAGE

9. Annual Volume Growth of Ponderosa Pine Before and After Thinning to 30 Basal Area Level 36

10. Annual Volume Growth of Ponderosa Pine--Comparison of Four Levels of Thinning, Before and After Thinning all Bolts 37

11. Annual Growth of Unthinned Ponderosa Pine During Two Time Periods 42

12. Annual Growth of Ponderosa Pine Before and After Thinning to 150 Basal ARea Level 43

13. Annual Growth of Ponderosa Pine Before and After Thinning to 80 Basal Area Level 44

14. Annual Growth of Ponderosa Pine Before and After Thinning to 30 Basal Area Level 45

15. Annual Volume Growth of Ponderosa Pine--Per Cent of Twelve Year Volume Comparison of Four Levels of Thinning Before and After Thinning all Bolts 46

16. Per Cent Latewood Volume--Annual Volume Relationship at Four Heights in Unthinned Ponderosa Pine During Two Time Periods 53

FIGURE PAGE

17. Per Cent Latewood Volume--Annual Volume Relationship at Four Heights in Ponderosa Pine Before and After Thinning to 150 Basal Area Level 54

18. Per Cent Latewood Volume--Annual Volume Relationship at Four Heights in Ponderosa Pine Before and After Thinning to 80 Basal Area Level 55

19. Per Cent Latewood Volume--Annual Volume Relationship at Four Heights in Ponderosa Pine Before and After Thinning to 30 Basal Area Level 56

20. Specific Gravity--Basal Area Per Acre Relationship in Ponderosa Pine by Height Levels 62

21. Specific Gravity--Per Cent Live Crown Relationship in Thinned Ponderosa Pine 63

22. Specific Gravity--Live Crown Volume Relationship in Thinned Ponderosa Pine 64

23. Specific Gravity--Live Crown Surface Area Relationship in Thinned Ponderosa Pine 65

FIGURE PAGE

24. Specific Gravity--Height Relationship in Ponderosa Pine Before (Rings 7-12) and After (Rings 1-6) Thinning to Four Basal Area Levels 67

25. Specific Gravity--Rings Per Inch Relationship in Ponderosa Pine, Before and After Thinning to Four Basal Area Levels 68

26. Specific Gravity--Latewood Width Relationship in Ponderosa Pine, Before and After Thinning to Four Basal Area Levels 69

27. Specific Gravity--Width of Six Ring Segment Relationship in Ponderosa Pine, Before and After Thinning to Four Basal Area Levels 71

28. Specific Gravity--Per Cent Latewood Relationship in Ponderosa Pine Before and After Thinning to Four Basal Area Levels 72

29. Specific Gravity at the Base of Each Bolt--Per Cent Latewood Volume of that Bolt Relationship in Ponderosa Pine, Before and After Thinning to Four Basal Area Levels . . . 74

30. Annual Radial Growth of Unthinned Ponderosa Pine During Two Time Periods 81

FIGURE PAGE

31. Annual Radial Growth of Ponderosa Pine Before and After Thinning to 150 Basal Area Level 82

32. Annual Radial Growth of Ponderosa Pine Before and After Thinning to 80 Basal Area Level . . 83

33. Annual Radial Growth of Ponderosa Pine Before and After Thinning to 30 Basal Area Level . . 84

34. Annual Radial Growth of Ponderosa Pine--Comparison of Four Levels of Treatment Before and After Treatment 85

35. Width of Six Ring Segment--Per Cent Live Crown Relationship During the Six Years After Thinning Ponderosa Pine to Four Basal Area Levels 88

36. Per Cent Live Crown--Basal Area Per Acre Relationship Six Years After Thinning Ponderosa Pine 89

37. Rings Per Inch--Basal Area Per Acre Relationship in Thinned Ponderosa Pine 91

38. Influence of Height on Tree Form, Before and After Thinning Ponderosa Pine 92

CHAPTER I

THE PROBLEM, OBJECTIVES AND SCOPE OF THE STUDY

There has only been seven thinning studies in the Southwest, all of them before 1937. These past thinning studies are of limited use to the present forest manager wishing to thin young-growth stands because they were only "light thinnings" and "crop tree releases" and left high residual basal areas (Schubert and Martin 1969). The present study collected data from very low to high residual basal areas.

In 1962 thinning plots were established in unit one of the Fort Valley Experimental Forest as part of a major study of ponderosa pine forests in the Western United States. This unit of the Fort Valley Experimental Forest is known as Taylor Woods and is located in Section 23, Range 6 East, Township 22 North of the Gila and Salt River Meridian. It consists of 90 acres and is covered with young even-aged ponderosa pine of 1919 origin (Schubert and Martin 1969). During September and October of 1962 the plots were thinned to six different basal area levels[1]

---

[1]The numerical designation of the level assigned a plot is the basal area per acre that will remain after thinning when stand diameter is 10 inches or more.

ranging from 30 to 150 square feet. Adjacent unthinned control plots were also established.

I. STATEMENT OF PROBLEM AND OBJECTIVES

Problem

Most of the ponderosa pine forests of the Southwest are overcrowded with natural reproduction which results in slow growth and, in many instances, stagnation. The recommended method of improving the growth characteristics of such stands is by release, through either commercial or pre-commercial thinnings, leaving those individual trees that have promising form. This raises the following questions: (1) how severe or thorough should these thinnings be to produce the best rate of growth while keeping wood quality high, and (2) should the same intensity of thinning be conducted on different aged stands, sites, elevations and aspects? Usually the most important question is, will thinning prove to be economical? The timber manager needs to know the answers to these questions so he can make intelligent decisions as to the products that the forest should be producing and the length of rotations for those products. This will enable him, through silvicultural practices, to better manage the ponderosa pine forests of the Southwest.

The Taylor Woods study is limited because it is only being performed on one site index. However, the knowledge gained by thinning to different basal areas, about the effects of thinning on wood quality, rate of growth, and volume growth can be enriched with this study. The site uniformity of Taylor Woods is also a factor contributing to the validity of the study. All the plots in this study have similar soil, precipitation, temperature, aspect, elevation, and site index.

Objectives

The objectives of this study were to: (1) determine the response to thinning at different basal area levels in terms of radial growth rate, volume growth, specific gravity, and per cent latewood, (2) compare the quality of the wood after thinning with that before thinning and with unthinned trees, and (3) establish relationships between selected environmental and morphological characteristics, and specific gravity and latewood width.

II. SCOPE OF THE STUDY

The samples for this study were taken from 24 trees sampled from four basal area levels of the Taylor Woods thinning plots.

CHAPTER II

REVIEW OF THE LITERATURE

A list of some of the factors found to contribute to specific gravity and the growth of latewood includes the following:

1. Soil
2. Site
3. Aspect
4. Elevation
5. Basal area
6. Per cent latewood
7. Growth rate
8. Precipitation
9. Soil moisture
10. Pruning
11. Ring width
12. Crown dimensions
13. Age
14. Temperature
15. Length of clear bole
16. Taper

The multiplicity of interactions of the above variables that affect wood quality and character of tree growth are indeed complicated. The relationship between soil, aspect, and elevation contributes to the site which then affects height and diameter growth which in turn affects crown and bole formation. Precipitation, as well as temperature, site and stand density affect the rate of growth which can affect the ring width and per cent latewood. With these complex interactions, it is very difficult to establish any one specific environmental

factor that will absolutely affect any one tree characteristic. This is difficult enough without including the factors of genetic control and auxin production.

In ponderosa pine (Pinus ponderosa, Laws.) it has been found by Conway and Minor (1961) and Cockrell (1943) that specific gravity decreases with increasing height. Wahlgren, Hart and Maeglin (1966) reported that "it has long been known that, for many conifers, specific gravity decreases with height in the tree." However, they also reported in the same article, that the specific gravity of spruce increases with height up the tree. This has also been shown by Hale and Fensom (1931). However in Englemann spruce (Picea engelmanii, Parry) it has been shown by Forrer (1968) that specific gravity is highest at the base, then decreases to 25 feet, then increases to 65 feet, and then decreases again. Paul (1957) reported that in red pine (Pinus resinosa, Ait.) specific gravity decreases up the tree as had been reported earlier for most conifers. However Cooper (1960) found very low correlation between specific gravity and height in red pine. Finally, Wahlgren, Baker, Maeglin and Hart (1968) found that in eight coniferous species in Maine there was no clear-cut relationship of specific gravity and height.

Since basal area or stocking greatly affects rate of diameter growth, both basal area and rate of growth will

be considered together as they affect specific gravity. Hale and Fensom (1931) and Keith (1961) working with white spruce (Picea glauca, Voss), Forrer (1968) with Englemann spruce, Paul and Meagher (1949) with ponderosa pine, Drow (1957) with Douglas fir (Pseudotsuga menziesii, Carr.), Echols (1958) with Scotch pine (Pinus sylvestris, L.), Hale and Prince (1940) with white spruce, and black spruce (Picea mariana, Mill.) and balsam fir (Abies balsamea, Mill.), Yandle (1956) with loblolly pine (Pinus taeda, L.), Paul and Smith (1956) with loblolly pine and longleaf pine (Pinus palustris, Mill.) and short leaf pine (Pinus echinata, Mill.) found that a fast growth rate resulted in a lower specific gravity. Of these studies, Paul and Smith (1956) and Paul and Meagher (1949) were made on thinned trees indicating that the increased growth due to lower levels of stocking resulted in lower specific gravity.

Paul (1963) reported that thinning increased the specific gravity of white ash (Fraxinus americana, L.), hickories (Carya sp.), rock elm (Ulmus thomasii, Sarg.) and oaks (Quercus sp.) which are all ring porous hardwoods. He also reports that black walnut (juglans nigra L.), a semi-ring porous hardwood, increases in specific gravity due to fast growth. This was also the case with sugar maple (Acer saccharum, March.) and yellow poplar

(Lirodendron tulipifera, L.) which are diffuse porous hardwoods. However, he reported that "unlike most hardwood species a number of species and hybrids of Populus decreased in a specific gravity due to fast growth."

Paul (1963) stated that in longleaf pine,

> accelerated growth following release, sometimes results in an increase in specific gravity and sometimes in a decrease and still at other times a considerable fluctuation occurred.

He also reported that in shortleaf pine when dominant trees were released the specific gravity decreased but when codominant trees were released they increased in specific gravity. In the same publication Paul reported that red pine, jack pine (Pinus banksiana, Lamb.), pitch pine (Pinus rigida, Mill.), Douglas-fir, redwood (Sequoia sempervirens, Endl.), sitka spruce (Picea sitchensis, Carr), white spruce, black spruce and red spruce (Picea rubens, Sarg.) increase in specific gravity as rate of growth slows. However, in Engelmann spruce and sugar pine (Pinus lambertiana, Dougl.) Paul further reported that there was little variation in specific gravity with varying growth rate. In eastern white pine (Pinus strobus, L.) "thinning did not increase specific gravity" (Paul 1963).

In another article Paul (1957) reported that thinning of red pine increased growth and specific gravity. Lowery and Schmidt (1957) reported that specific gravity of

thinned western larch (Laris occidentalis, Nutt.) increased most on plots having the least basal area stocking. However, Cooper (1960) working with red pine, McKimmy (1959) with Douglas-fir, Zobel and Rhodes (1955) with loblolly pine, McGinnes (1963) with shortleaf pine, and Fielding and Brown (1960) with Monterey pine (Pinus radiata, D. Don.) reported little correlation between specific gravity and rate of growth. Smith (1968) reported for loblolly pine that a "threefold increase in radial growth was found to be accompanied by a significant increase in specific gravity and percentage of latewood in response to heavy thinning and pruning."

McKimmy (1959) found that in young growth Douglas-fir "a constant rate of growth with differing percentages of summerwood[1] caused more variation in specific gravity than did a constant percentage of summerwood under differing rates of growth" and "percentage of summerwood in general, tended to influence specific gravity more than did growth rate." Paul and Smith (1956) and Zahner (1958) believed that a high percentage of summerwood contributes to high specific gravity of Southern pine. Drow (1957) found that an increase in specific gravity resulted from

---

[1]For this study earlywood is synonymous with springwood and summerwood with latewood.

increases in per cent of summerwood in Douglas-fir. Zobel and Rhodes (1955) found the same results in loblolly pine. Schafer (1949) found, in working with a number of specimens of the four Southern pine species analyzed together, that "72% of the total variation in specific gravity was attributable to the variation in volume of summerwood." Smith (1968) reported that for thinned loblolly pine, "a change in the relationship between specific gravity and percentage of latewood suggested that there were fundamental changes in the wood structure associated with thinning and pruning." Thinning also produced earlywood tracheids that were narrower and latewood tracheids that were wider than those found in the unthinned stands.

Cooper (1960) found low correlation between specific gravity and average annual precipitation in red pine. Hale and Prince (1940) reported that as summer T-E[1] increased so did the specific gravity of both black and white spruce. Fielding and Brown (1960) found "no correlation between the specific gravity of the wood of Monterey pine and any external, morphological characteristics of the tree." Wahlgren, Baker, Maeglin and Hart (1968) found no relationship to forest type. McKimmy

---

[1]T-E: Thornthwaite's thermal efficiency on summer concentration, a measure of the effective temperature over 32°F.

(1959) reported that "site, crown class and geographical location appeared to have little effect on specific gravity." With yellow poplar, Paul (1963) found that climate, soil, or elevation had no correlation with specific gravity. Voorhies (1969b) found low correlation between specific gravity and age, basal area, site index, aspect, and soil properties. However, he hinted at a relationship with precipitation and temperature because of a significant correlation between elevation and specific gravity in ponderosa pine.

In conclusion, specific gravity is probably the result of a number of interacting edaphic and climatic factors (Fielding and Brown 1960). "Differences in specific gravity between pieces of wood reflect differences in cell wall thickness, packing density, cell diameter, cell length, amount of extractive, and volume of mechanical tissue" (Western Wood Density Survey 1965). "Specific gravity variations must ultimately be explained on anatomical variations which in turn are in part physiologically regulated" and finally must be due to changes in the wall-to-lumen ratio (Hall 1963).

It is universally agreed that thinning or any kind of lower stand density results in a greater volume growth and rate of diameter growth per tree. A few of those authors that have reported such findings are: Lowery and

Schmidt (1967), Zahner (1958), Paul (1957, 1963), Paul and Smith (1956), Smith (1968) and, in ponderosa pine, Krauch (1924), Schubert and Martin (1969) and Paul and Meagher (1949).

Zahner (1958) stated that, for Southern pines:

> Increasing the summerwood percentage in the growth ring will raise specific gravity. This may be done in two ways: (1) by increasing the water-retaining ability of the soil, thus keeping the trees growing for a longer time toward the close of the season; and (2) by maintaining a stand so fully stocked that crown development will be restricted. Such restriction of crown development will also be accompanied by a lesser production of springwood.

Chalk (1930) reported that, for Douglas-fir, a high correlation was found between latewood volume and June-July-August rainfall. Gaertner (1961) found a high correlation between late season basal area growth and any new available soil moisture for both pine and oak.

Kramer (1964) believed that the amount of latewood formed depends largely on the water supply late in the growing season. Bannan (1962) stated that

> while the development of latewood usually takes place when available soil moisture is at a low level, it is significant that an increase in water supply at this time of year is reflected in expanded latewood production.

He also thought that latewood formation is not caused simply by a low water supply. Larson (1964) believed that environmental factors directly affect crown development

which affects wood formation. Therefore, he believes, environmental factors indirectly affect wood formation.

It has been shown that cooler nightime temperatures with warm daytime terperatures increased cell wall thickness in redwood and Douglas-fir and that warm days and warm nights produced large diameter cells in the same species where warmer night time temperature seems to have more effect than daytime temperature (Richardson 1964, Dinwoodie and Richardson 1960). Richardson (1964) found that in Pinus radiata cell wall thickness decreased with increasing night temperature. Hellmers (1962) stated that "trees (for optimum growth) need a day and night temperature differential and there is an optimum differential for each species."

Zahner (1958) said that "enlarged crowns produce springwood more abundantly" than small crowns; this has also been reported by Glock (1955) and Marts (1949, 1950). Paul and Smith (1950) reported that

> the growing space will affect competition among the trees for soil moisture and sunlight and will be reflected in the size of the crown. Regulation of crown size can have a two-fold result (1) clear lumber from pruning and (2) increased wood density from curtailment of springwood development.

Chalk (1930) measured the basal area of the crown, ovendry weight of the needles and the surface area of the cone formed by the crown. He found that the ovendry weight of

the needles was the best measurement when relating the crown to formation of summerwood or density. Bannan (1962) reported that defoliation results in a marked reduction in latewood, and that open-grown trees have more latewood. Larson (1962) has found that "crown size and distribution of the branches within the crown" are the important factor in the formation of wood. He also reported that "numerous studies of stem form have shown that trees with long, vigorous crowns produce strongly tapering stems with a rather high proportion of earlywood to latewood," and, "once initiated, cambial activity proceeds more vigorously, and the period of earlywood formation extends for a longer time in the large-crown individuals." Larson also reported that "crown size also exerts an influence on the abruptness of the earlywood-latewood transition." Longer crowned trees have a gradual transition.

Paul and Marts (1954) reported that in longleaf pine latewood production is underway by mid-May to mid-June. Bannan (1962) says that for "Picea in northern temperature latitudes, the time of latewood inception has been given as mid-June through mid-August."

According to Larson (1962) there is

> no activity during dormancy in the spring. Bud swell is the first indication of auxin activity that can be detected and the first cambial activity is just below the bud. As the buds continue to

> expand and the new leaves unfold, the wave of cambial activity progresses down the main stem and branches and eventually envelopes the entire bole.

He reported that a growing bud is needed, because if it is decapitated latewood is formed. He also stated that

> cambial activity, including xylem development is regulated by an auxin system controlled directly by the activity of the terminal meristems, and in red pine it is clearly evident that latewood is initiated at the termination of height growth.

According to Wort (1962) "the change from the production of earlywood to latewood may thus be a response to a changed level of auxin reaching the cambium, coupled with a specific response to a diminishing hormone supply." If the threshold is sharp there will be an abrupt transition. Kramer (1964) stated that "relationships of auxin-to-cambial activity may vary considerably among different species."

It is the job of the silviculturist to effect the change of environment that will promote a better product from his forest land through thinning and pruning.

CHAPTER III

EXPERIMENTAL DESIGN AND PROCEDURES

The following was taken from "Study Plan FS-RM-1203.35, Wood Quality of Young-Growth Ponderosa Pine after Thinning" with a few changes and additions. The plan was prepared by Mr. Glenn Voorhies for a cooperative study between the Northern Arizona University School of Forestry and the Rocky Mountain Forest and Range Experiment Station. This research is part of that cooperative study.

I. PROCEDURES

Thinning Plots

The Taylor Woods thinning plots were the source of the sample material. Plots thinned to basal area levels[1] of 30, 80, and 150 square feet per acre were the study groups. Actual basal area per acre was checked by using a ten factor basal area prism.

Trees

Six trees representative of each basal area level (two trees from each of the three replicated plots) were selected in the adjacent buffer strips on a random basis.

---

[1]The numerical designation of the level assigned a plot is the basal area per acre that will remain after thinning when stand diameter is 10 inches or more.

In order to relate the trees selected to the present (1969) actual level of basal area per acre, the stand density around each selected stem was checked with a ten factor area prism. This 1969 basal area was used in some calculations.

Field Data

The following information was determined and recorded for each tree.

1. Diameter Breast Height (DBH)
2. Total height
3. Length to first live limb
4. Length of crown
5. Width of crown at base and at mid-height

Tree Processing

1. Each sample tree was felled using a cut as close to ground level as possible. The butt was cross-cut to level the cross-section area.
2. Bole sections one foot in length were cut from the base of the tree and at 5', 10', 15', 20', and 30'. Each bole section was labeled with non-soluble ink. The clearest five-inch section of this piece was used in laboratory analysis.
3. The sections were stored in a water bath prior to laboratory analysis.

Laboratory Processing

1. Each five-ince section was measured as follows:
   a. Diameter outside bark (D.O.B.) and diameter inside bark (D.I.B.) with a diameter tape.
   b. Rings from pith (age) detected under magnification.
2. One 3/8-inch thick disk was sawn from all of the five-inch sections and the average radius determined. Along the average radium a section approximately 3/8-inch wide by 12 rings from the bark in the radial direction was sawn and severed from the section.
   a. The six-ring segment after thinning was excised from the 12-ring segment.
   b. Both the unthinned segment and the thinned segment were subjected to specific gravity determination by the water immersion method. While in process the individual segments were clearly identified as to tree and height level. Data were recorded on appropriate forms.
3. The same before and after thinning sections were used to evaluate the amount of water-soluble and benzene-soluble extractives in the 12-ring segment.
   a. Each segment was first subjected to extraction in distilled hot water. The material under study was placed in a double boiler with distilled water and heated to boiling for a period of at least 30

hours with water changes every four hours. The segments were oven-dried and the per cent of water soluble extractives determined.

b. Using the same oven-dried sample above, extraction of pitch and other hydrocarbons was made with 33% ethyl alcohol and 67% benzene solution for a total extraction period of at least 30 hours. Based on the oven-dry weight before and after extraction, the per cent extractives was computed.

4. One 3/8-inch disk was sawn from the five-inch section and the average radius determined.

a. Along the average radius, a segment was cleaned and smoothed from the pith to the edge.

b. This segment was placed under the dendrochronograph and the number of rings from the pith was determined.

c. Starting at the 13th ring from the bark and working toward the bark the width of the earlywood and latewood of each ring was estimated using the dendrochronograph. The results were used to determine the total volume, the volume of earlywood and the volume of latewood and percentage of latewood. Accumulated volume was calculated using the formula:

$$Vol_N = ii\left(\frac{R_B + R_T}{2}\right)^2_N \times Ht$$

where: Vol = Accumulated volume (cubic inches)

N = Ring number

ii = 3.14159

R = Radius from the pith to ring number N (inches)

Ht = Height of bolt (60 inches)

B = Base of bolt

T = Top of bolt

Annual volume was then calculated by subtracting the accumulated volume through ring number "N" from the accumulated volume through ring number "N + 1."

5. All residual sections were cut along the average diameter, labeled and stored for possible future reference.

II. ANALYSIS OF RESULTS

1. All data relevant to each tree (which will include all height levels) were recorded and tabulated on forms (shown in the appendix) designed for all of the specified information.
2. The above data were transferred to IBM punch cards, using one card for each period (before and after

thinning) of each height level for each tree. The data appeared on punch cards approximately as follows:

a. Tree number
b. Height level
c. Specific gravity of each six-ring increment
d. Ring width of six-ring segment
e. Per cent latewood
f. Latewood width
g. Latewood volume
h. Bole section volume
i. Crown (Volume and Surface) area
j. August and September temperature (average day and night by months)
k. Rings per inch
l. Basal area
m. August and September rainfall (averaged by months)

Since site and soil type are common to all plots, these variables were not included.

Analysis of Data

Multiple regression analysis, using an all-possible variable program was employed to establish the following principal relationships.

	Dependent Variable	Independent Variable
(1)	Specific gravity	Basal area plus variables shown under tabulation-2 above
(2)	Per cent of latewood	as above
(3)	Ring width or rings per inch	as above
(4)	Actual latewood width and volume by years	Crown (surface and volume), temperature and rainfall averaged by months

CHAPTER IV

EXPERIMENTAL RESULTS

There were two ways to evaluate the treated period in this study, (1) comparison with the pretreatment data and (2) comparison with the control data during the same period as treatment. Regression analysis was used to calculate predictive equations for the pretreatment, control, and treated data for each of the basal area levels studies. The other statistical analyses utilized were an unpaired "t" test and analysis of variance. The "t" test was used to compare rings 7-12-vs-1-6 at each height in each of the basal area levels studied. (When rings 7-12 or 1-6 are referred to in this paper they are numbered from the bark and are before and after thinning respectively.) The analysis of variance was used to analyze differences within each variable measured between heights and between levels of treatment. This was done to determine if there were any inherent differences between the two time periods in the untreated data and then to analyze any differences due to levels of thinning. For the purposes of this report any statistical significance reported exceeds the five per cent level.

I. VOLUME GROWTH

It can be said that volume growth per tree can be increased by thinning. This is shown in the following discussion.

Accumulated Volume

The pretreatment data showed no significant correlation with the year of formation, except in two cases. Both of the exceptions were in the fourth bolt, one in the control data and one in the pre-80 basal area data. There were no significant correlations with the year of formation in the control data during the treated period; however all heights in all the thinned data, with one exception, showed significant correlations with the year of formation. The one exception was in the third bolt of the 150 basal area level (Figure 1-5, Appendix Table XIII).

Using the pretreatment period as a base, the control trees increased in accumulated volume by 14.5 per cent on the first bolt to 59.6 per cent on the fourth bolt and an average of 26.7 per cent per tree during the treatment period. The increase in each bolt, except the first, and all combined was significant. The average accumulated volume of the 150 basal area level increased 43 per cent, the 80 basal area level increased 57 per cent and the 30 basal area level increased 59 per cent when compared to

ACCUMULATED VOLUME GROWTH OF UNTHINNED PONDEROSA PINE DURING TWO TIME PERIODS

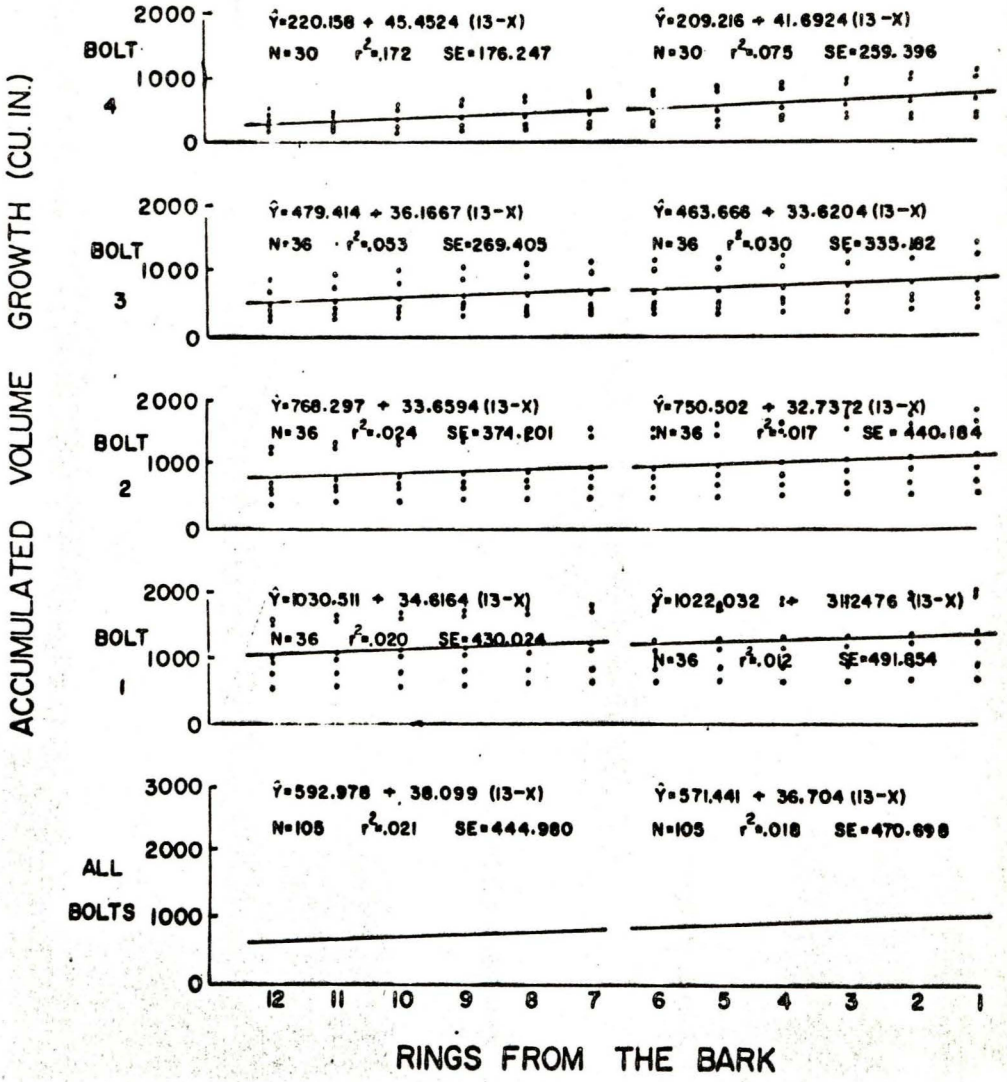

Figure 1

ACCUMULATED VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 150 BASAL AREA LEVEL

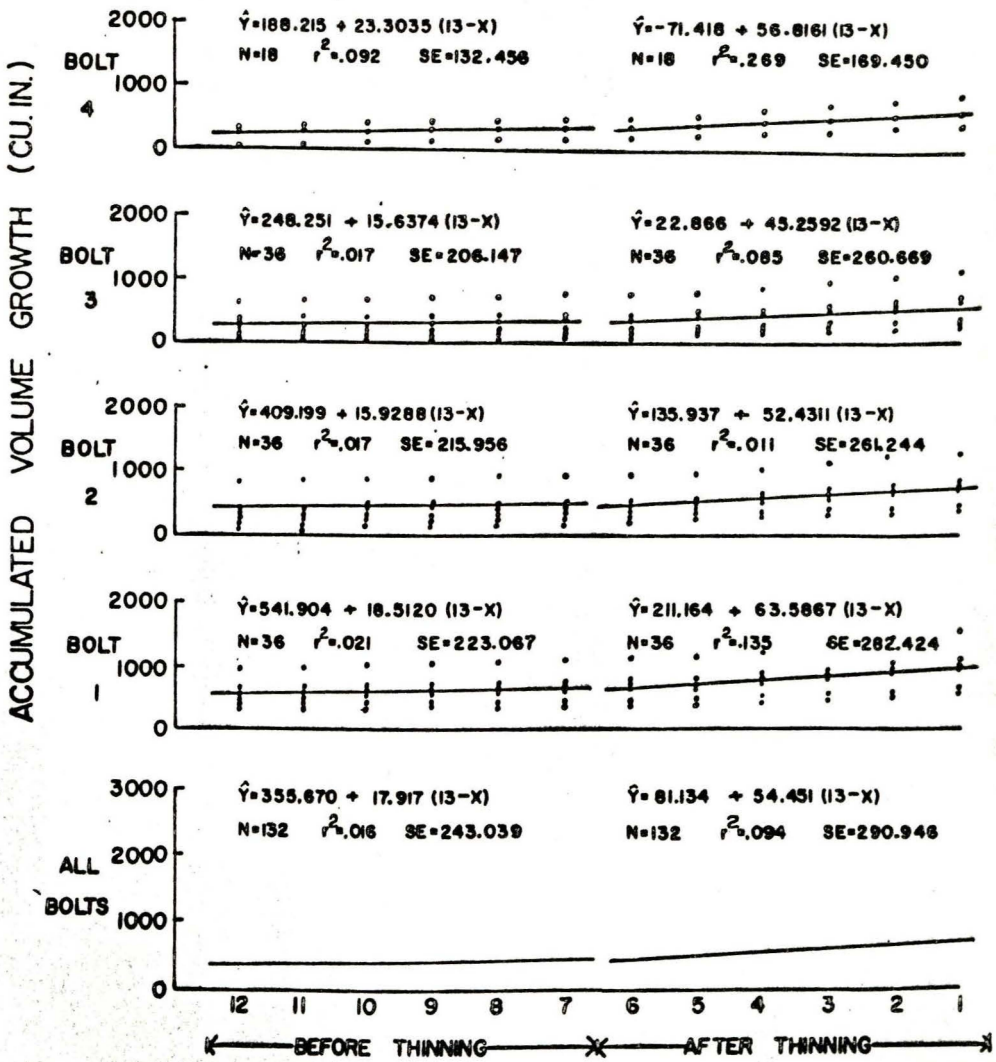

Figure 2

ACCUMLATED VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 80 BASAL AREA LEVEL

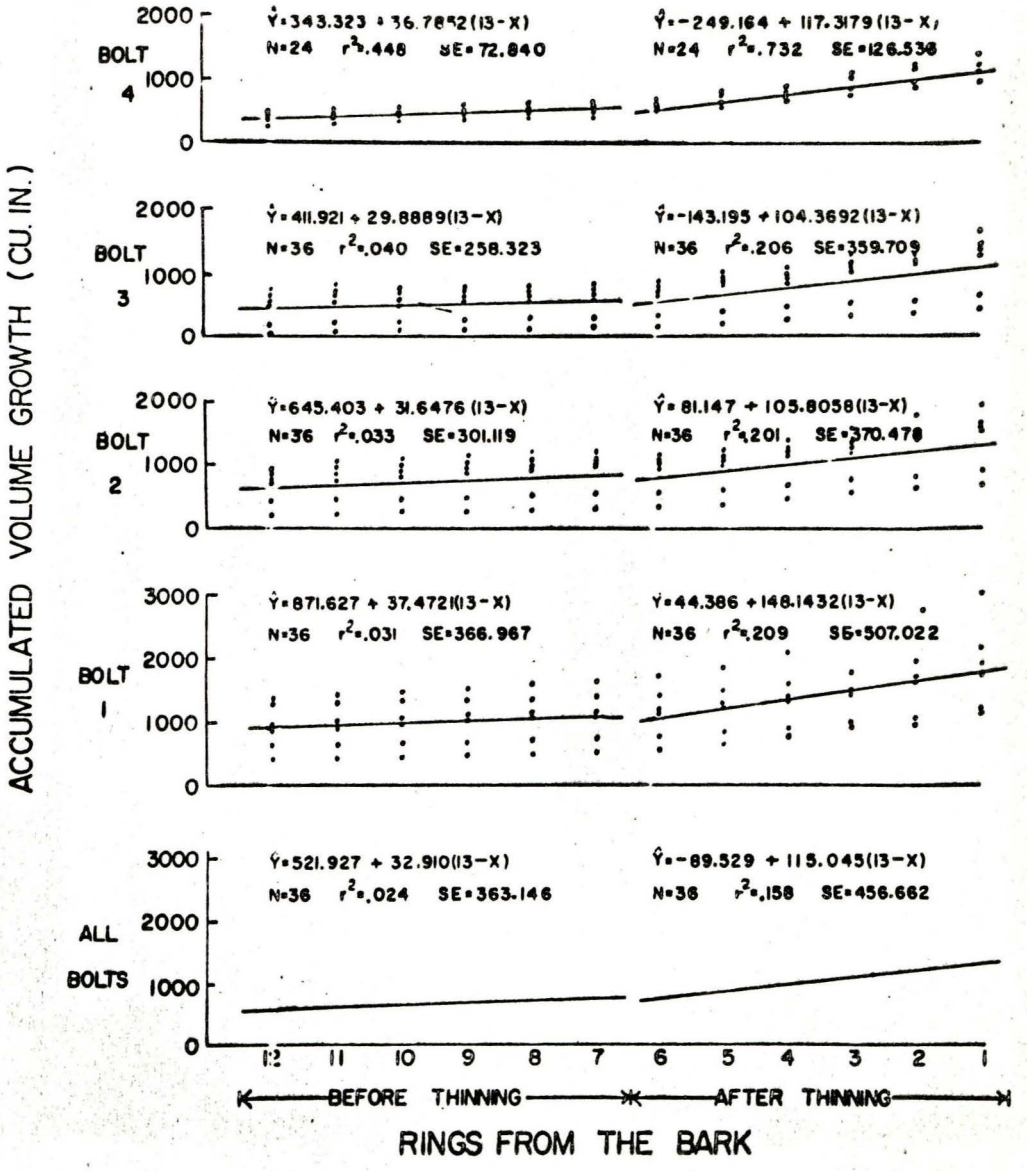

Figure 3

ACCUMULATED VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 30 BASAL AREA LEVEL

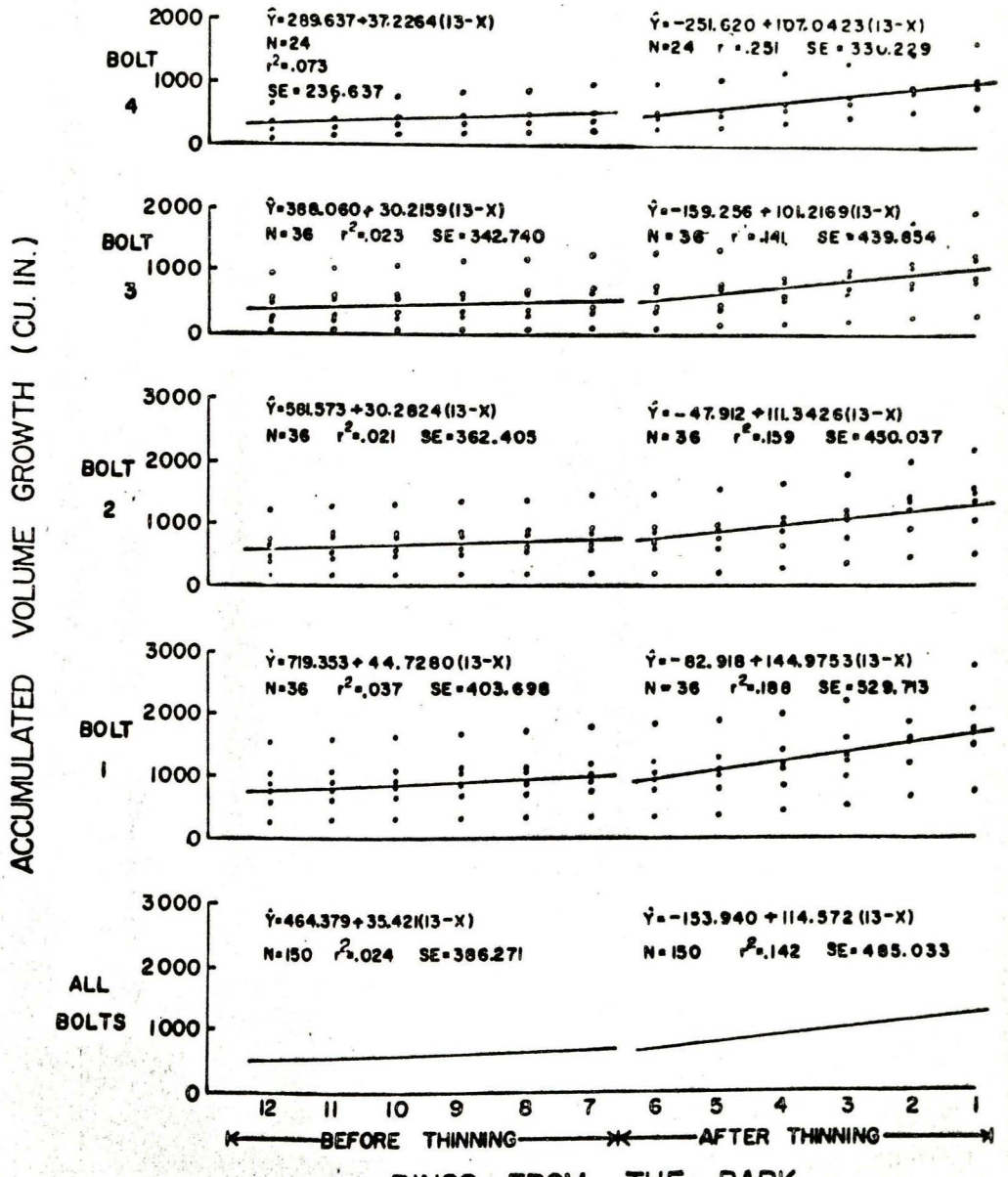

Figure 4

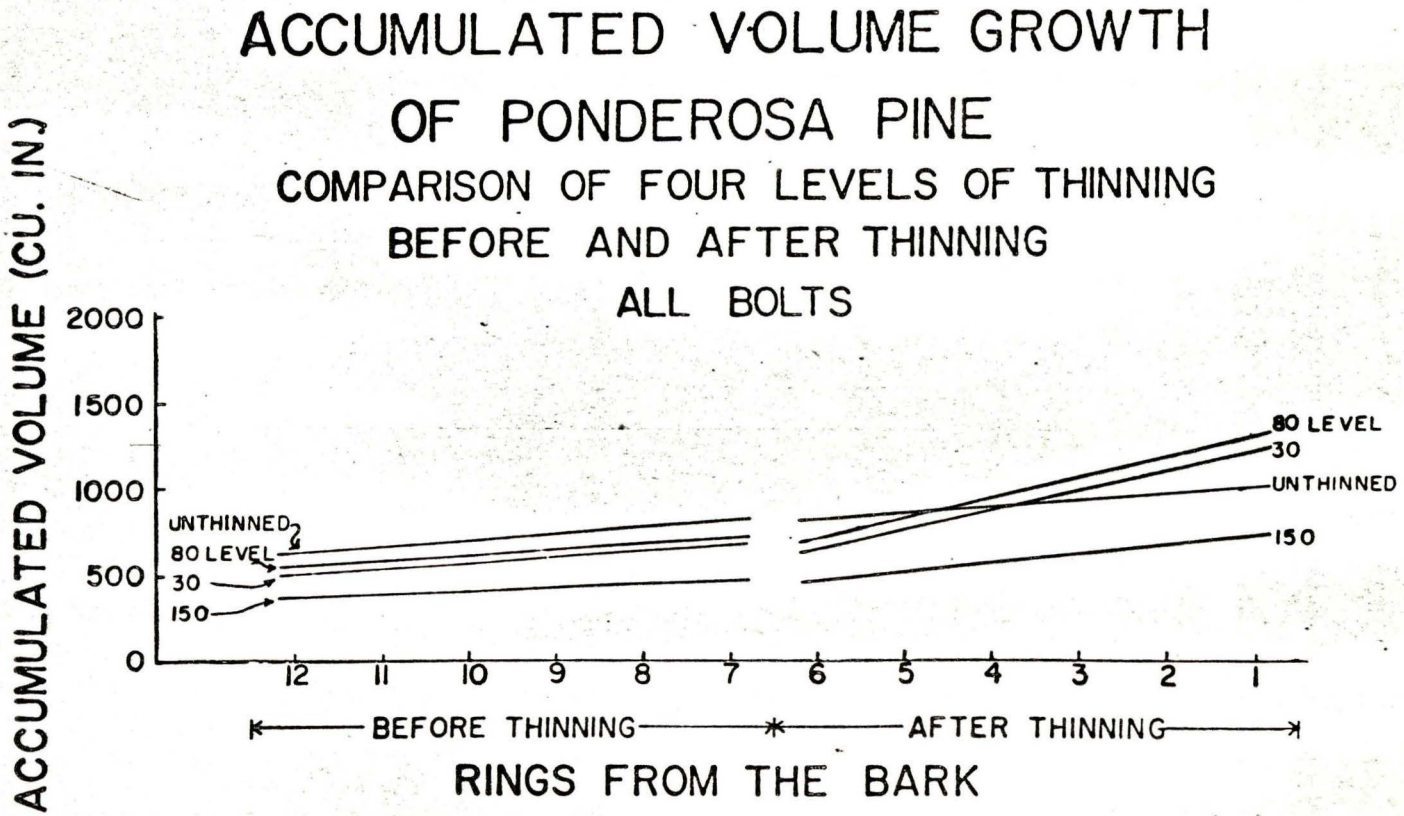
ACCUMULATED VOLUME GROWTH
OF PONDEROSA PINE
COMPARISON OF FOUR LEVELS OF THINNING
BEFORE AND AFTER THINNING
ALL BOLTS
ACCUMULATED VOLUME (CU. IN.)
2000
1500
1000
500
0
UNTHINNED
80 LEVEL
30
150
80 LEVEL
30
UNTHINNED
150
12
11
10
9
8
7
6
5
4
3
2
1
BEFORE THINNING
AFTER THINNING
RINGS FROM THE BARK

Figure 5

the six year pretreatment period. In every bolt of every thinned level the increase was significant (Table I).

The analysis of variance of accumulated volume between bolts of the control data showed significant differences, during both time periods, in every case but one. The one exception was during the after treatment period in which there was no difference between bolts three and four (Appendix Tables XXI and XXII). The 150 basal area level showed that there were significant differences, both before and after thinning, of accumulated volume between bolts. This was true except that in both before and after thinning data there was no significant difference between bolts three and four (Appendix Tables XXIII and XXIV). In the 80 basal area level the pretreatment data showed significant differences of accumulated volume between bolts, except there was no significant difference between bolts two and four and between three and four (Appendix Tables XXV and XXVI). The 30 basal area level showed the same results as the 80 basal area level plus there was no significant difference between bolts two and three for the after thinning data (Appendix Tables XXVII and XXVIII).

Analysis of variance showed significant differences between the accumulated volume of all treatment levels, with one exception, before thinning. The one exception

TABLE I

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF ACCUMULATED VOLUME BY HEIGHTS OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt No.	Rings 7-12 N	Rings 7-12 Mean Cu.In.	Rings 1-6 N	Rings 1-6 Mean Cu.In.	% Incr. or Decr.	DF	$S.E._d$	"t" (one tailed)
Unthinned	1	36	1152	36	1319	14.52	70	108.16	1.546NS
	2	36	886	36	1062	19.79	70	95.87	1.829*
	3	36	606	36	783	29.22	70	72.06	2.457*
	4	30	379	30	605	59.60	53	59.56	3.795**
	All	150	726	150	920	26.68	298	53.23	3.641**
150 Basal Area Level	1	36	607	36	815	34.37	65	62.13	3.356**
	2	36	465	36	634	36.37	70	57.88	2.921**
	3	36	303	36	452	49.46	70	56.31	2.661**
	4	18	270	18	468	73.60	34	55.37	3.586**
	All	132	418	132	598	43.03	250	33.96	5.301**
80 Basal Area Level	1	36	1003	36	1452	44.77	60	111.88	4.013**
	2	36	756	36	1086	43.66	64	84.66	3.900**
	3	36	517	36	848	64.23	60	79.21	4.189**
	4	24	472	24	865	83.31	30	52.60	7.477**
	All	156	637	156	1003	57.49	285	49.37	7.419**
30 Basal Area Level	1	36	876	36	1294	47.77	63	117.84	3.551**
	2	36	688	36	1010	46.87	65	100.60	3.204**
	3	36	494	36	802	62.47	64	96.54	3.195**
	4	24	420	24	765	82.24	39	90.62	3.811**
	All	150	588	150	934	58.83	276	53.17	6.510**

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

was that there was no significant difference, for the pre-treatment data, between the 80 and 30 levels. Thinning reduced these differences because there were no significant differences, for the treated period, between the control and 80 level, the control and 30 level or between the 30 and 80 level. All other combinations showed significant differences for the thinned period, (Appendix Tables XXIX and XXX).

Because of the fact that accumulated volume growth is related to the size of the tree, the forgoing analysis can be questioned. The average size of the trees are different for each level and thus volume growth expressed in cubic inches has its deficiencies. The better way to analyze the effect of thinning on accumulated volume growth is to analyze the per cent increases, thus, taking out part of the inherent effects of diameter differences. Because any amount of diameter growth will increase the volume of a tree it can be seen that the control trees increased in accumulated volume. However, the important observation is that per cent increase in accumulated volume decreases with increasing basal area and that there is a higher per cent increase in accumulated volume higher in the trees.

Annual Volume

The correlation coefficients between annual volume and the year of formation were all non significant for all bolts of all treatment levels for the pretreatment data and significant for both the control and treated data during the after treatment period (Figures 6-10, Appendix Table XIII).

The control trees showed a decrease in the average annual volume growth during the treated period over the pretreatment period. The average annual decrease was 17.4 per cent per tree. The decrease was significant in all bolts but the fourth. In all heights of all thinned levels, there was a significant average annual increase over the prethinned period. The average annual increase was 159 per cent in the 150 level, 199 per cent in the 80 level and 196 per cent in the 30 level (Table II).

Analysis of variance showed no significant differences in annual volume growth between bolts for either the pretreatment or treated period for both the control (Appendix Tables XXXI and XXXII) and 30 level (Appendix Tables XXXVII and XXXVIII). The 150 basal area level had a significant difference for the pretreatment data between bolts one and four, two and four and three and four. However, there was no significant difference between bolts after thinning. Data for the 80 basal area level showed

ANNUAL VOLUME GROWTH OF UNTHINNED PONDEROSA PINE DURING TWO TIME PERIODS

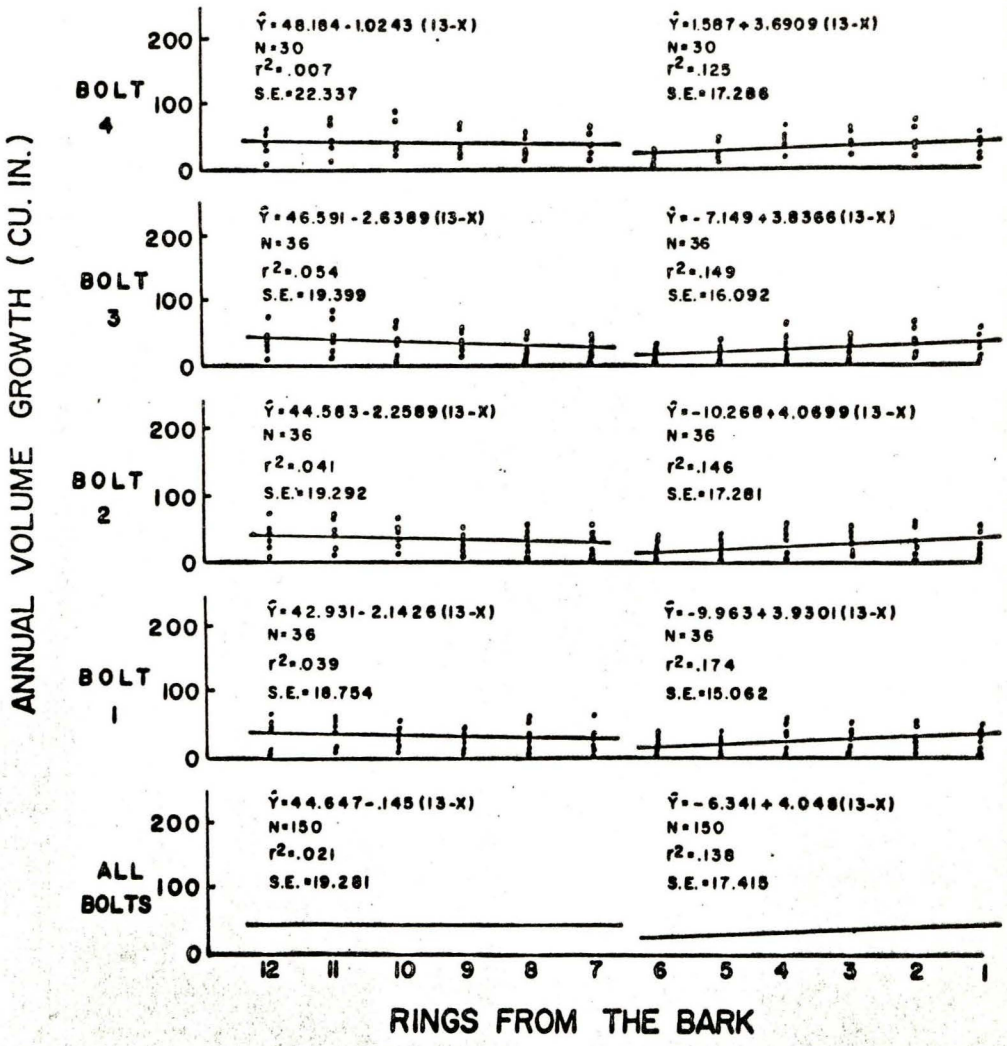

Figure 6

ANNUAL VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 150 BASAL AREA LEVEL

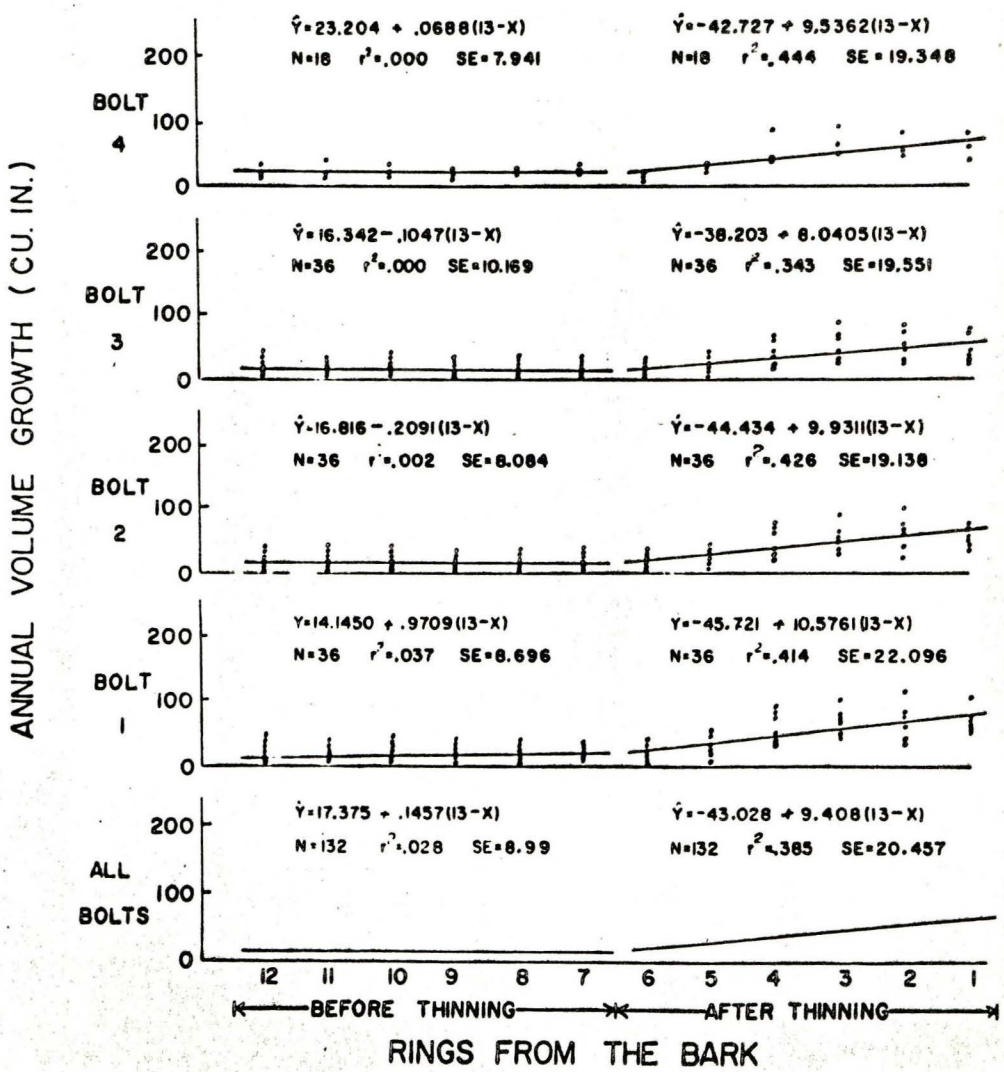

Figure 7

ANNUAL VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 80 BASAL AREA LEVEL

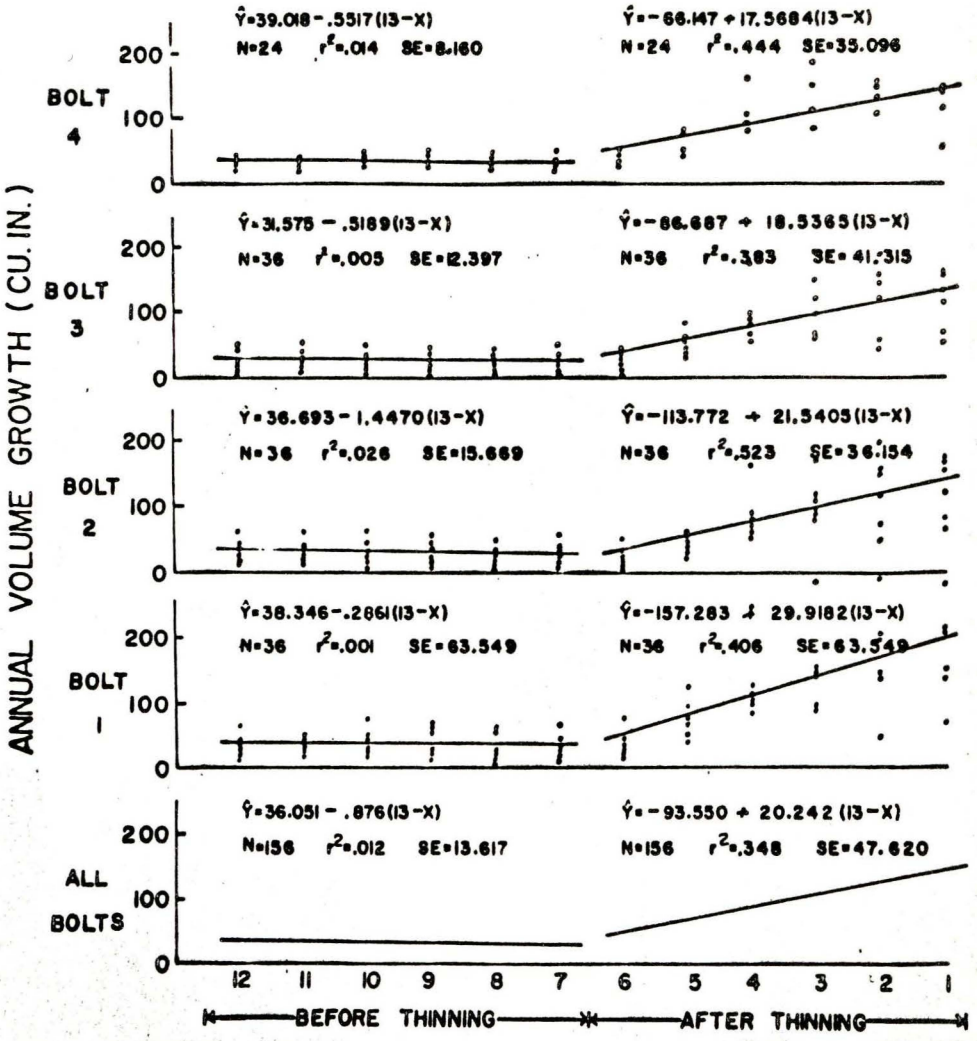

Figure 8

ANNUAL VOLUME GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 30 BASAL AREA LEVEL

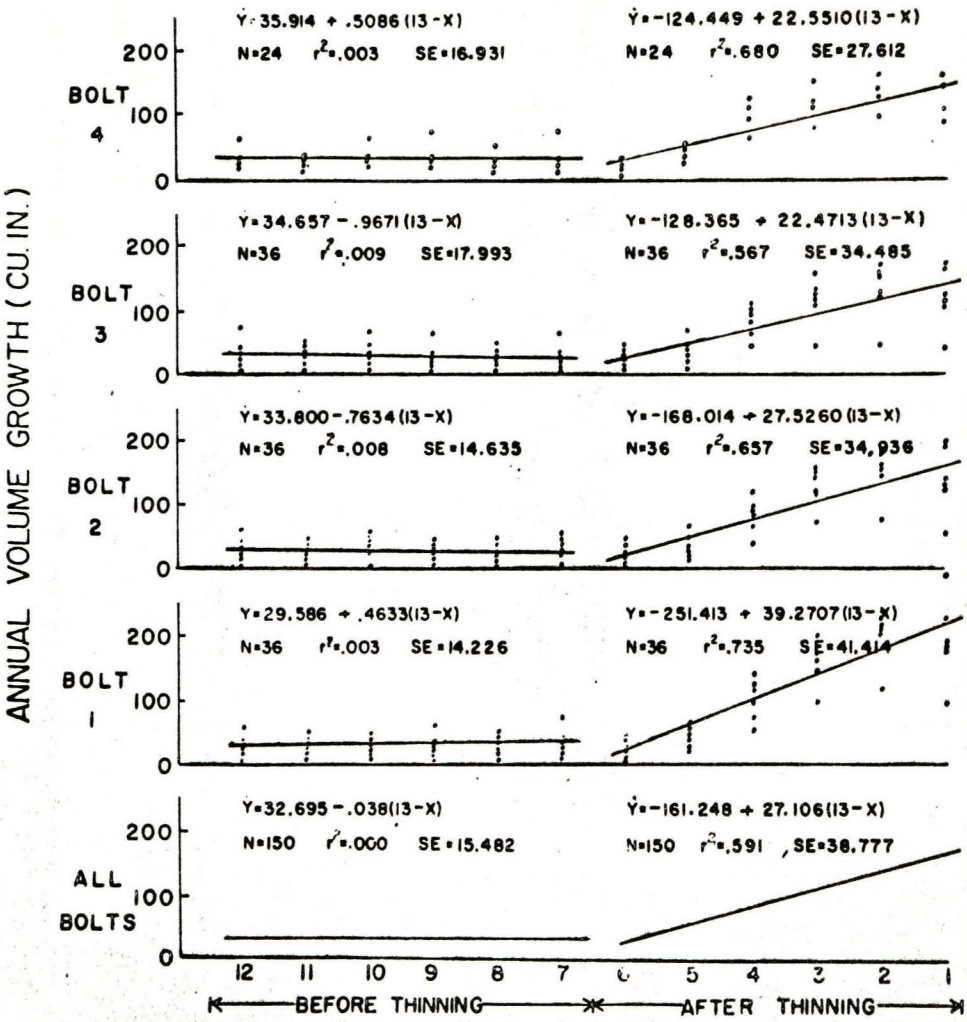

Figure 9

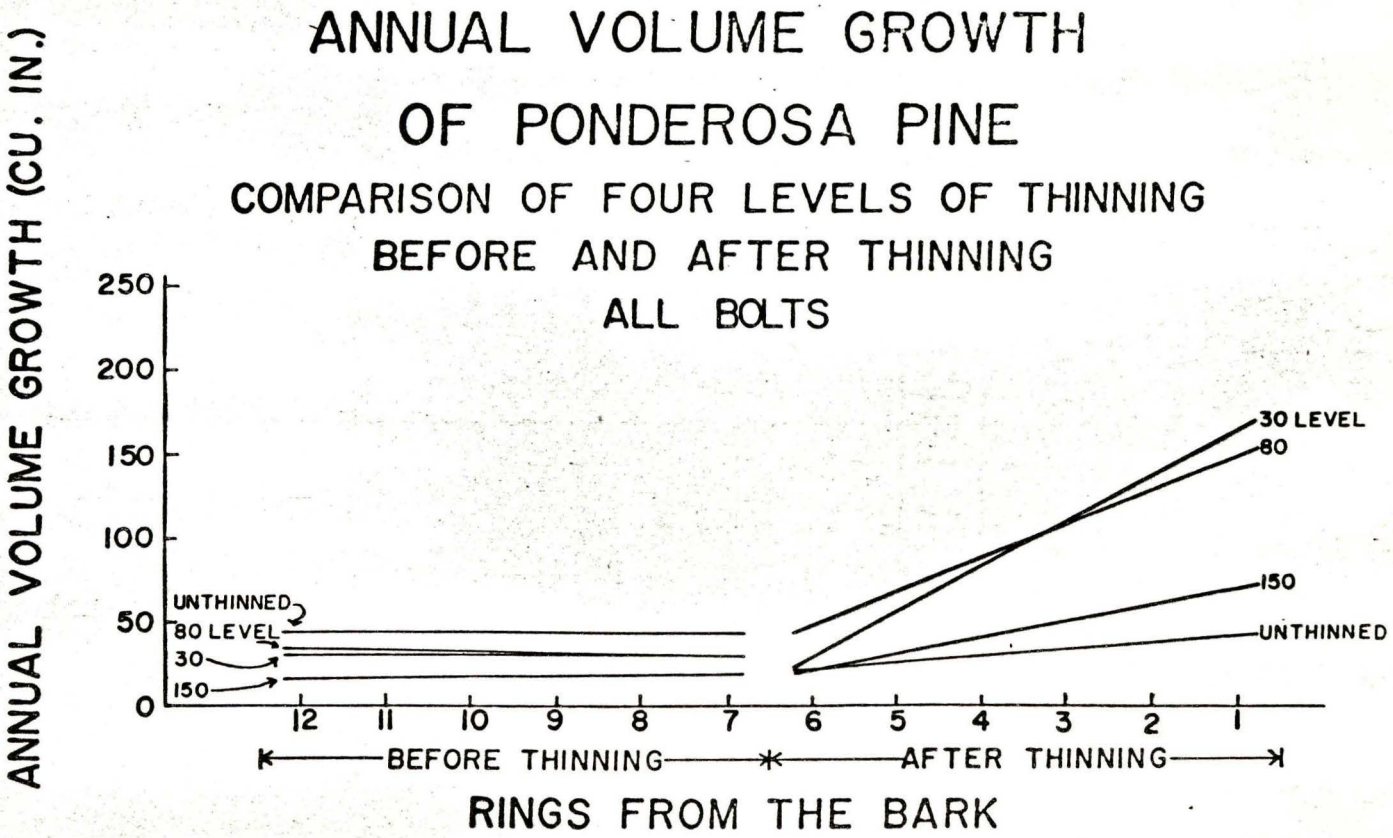
ANNUAL VOLUME GROWTH
OF PONDEROSA PINE
COMPARISON OF FOUR LEVELS OF THINNING
BEFORE AND AFTER THINNING
ALL BOLTS
ANNUAL VOLUME GROWTH (CU. IN.)
250
200
150
100
50
0
UNTHINNED
80 LEVEL
30
150
30 LEVEL
80
150
UNTHINNED
12 11 10 9 8 7 6 5 4 3 2 1
BEFORE THINNING
AFTER THINNING
RINGS FROM THE BARK

Figure 10

TABLE II

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF ANNUAL VOLUME BY HEIGHTS OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt No.	Rings 7-12 N	Rings 7-12 Mean Cu.In.	Rings 1-6 N	Rings 1-6 Mean Cu.In.	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	1	36	35.4	36	27.4	-22.7	70	4.16	1.939*
	2	36	36.7	36	28.4	-22.6	70	4.46	1.856*
	3	36	37.4	36	29.3	-21.6	70	4.35	1.851*
	4	30	44.6	30	36.7	-17.8	58	5.21	1.525NS
	All	150	38.9	150	32.1	-17.4	298	2.20	3.074**
150 Basal Area Level	1	36	17.8	36	54.8	206.8	42	4.96	7.438**
	2	36	16.1	36	44.8	178.4	42	4.36	6.583**
	3	36	16.0	36	38.2	139.0	47	4.30	5.164**
	4	18	23.4	18	47.9	104.2	20	6.20	3.937**
	All	132	17.9	132	46.3	159.1	162	2.39	11.895**
80 Basal Area Level	1	36	37.3	36	126.9	239.9	38	13.84	6.476**
	2	36	31.6	36	90.9	187.3	41	8.99	6.592**
	3	36	29.8	36	89.4	200.4	39	8.88	6.717**
	4	24	37.1	24	100.8	171.7	24	9.54	6.677**
	All	156	33.0	156	98.8	199.4	172	4.83	13.610**
30 Basal Area Level	1	36	31.2	36	121.7	289.8	37	13.43	6.737**
	2	36	31.1	36	93.5	200.3	39	10.09	6.177**
	3	36	31.3	36	85.1	172.2	43	9.11	5.910**
	4	24	37.7	24	89.8	138.2	28	10.31	5.052**
	All	150	32.6	150	96.3	195.6	168	5.09	12.510**

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

no significant difference of annual volume growth between bolts for the pretreatment period but showed significant differences between bolts one and two and one and three for the thinned data (Appendix Tables XXXV and XXXVI).

Analysis of variance showed significant differences in annual volume growth between all levels, except the 30 and 80, for both the before and after thinning periods (Appendix Tables XXXIX and XL).

Per cent average annual volume growth was increased by thinning with progressively less response higher in the tree (Table II). Yet, in general, there was no significant difference between bolts (Appendix Tables XXXI-XXXVIII).

Differences between levels reflected the inherent differences in tree diameter between thinning levels.

Annual Volume Growth--Per Cent of the Twelve Year Volume

To remove the effects of diameter differences between thinning levels on volume growth, annual volume was expressed as a per cent of the twelve year volume (six years prior to treatment plus six years after treatment).

The average annual per cent of twelve year volume for the control data during the pretreatment period was 9.1 and for the treated period was 7.5. Thus, the annual volume growth for the unthinned trees was decreasing. The 150 level showed, on the average, that 12.1 per cent of the

twelve year volume was formed annually for the six years after thinning. The trees in the 80 level formed 12.4 per cent while the trees in the 30 level formed 12.6 per cent of the twelve year volume per year after thinning (Table III, Figures 11-15).

Trees in unthinned stands would be expected to decrease in annual volume growth per tree while thinned stands increased. The average annual per cent of twelve year volume decreased with increased basal area.

Earlywood and Latewood Volume

The unthinned trees showed decreases in both earlywood and latewood volume (earlywood 20.1% and latewood 1.6%), however only the decrease in earlywood volume was significant. Earlywood volume increased 170 per cent in the 150 basal area, 205 per cent in the 80 level and 208 per cent in the 30 level while the latewood volume increased by 97 per cent in the 150 level, 169 per cent in the 80 level and 147 per cent in the 30 level. All increases, both earlywood and latewood volumes, were significant. All relationships, in earlywood volume, between levels remained the same before and after thinning (TablesV and VI, Appendix Tables LI-LIV). The relation between earlywood volume and latewood volume changes, and thus results in the differences or no difference, as the case may be, in per

TABLE III

COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF ANNUAL VOLUME GROWTH--PER CENT OF 12 YEAR VOLUME BY HEIGHTS OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt Number	Rings 7-12		Rings 1-6		% Incr. or Decr.
		N	Mean %	N	Mean %	
Unthinned	1	36	9.3	36	7.4	-20.3
	2	36	9.5	36	7.2	-24.3
	3	36	9.3	36	7.3	-21.1
	4	30	9.0	30	7.4	-17.4
	All	150	9.1	150	7.5	-18.3
150 Basal Area Level	1	36	4.0	36	12.6	212.7
	2	36	4.3	36	12.4	190.9
	3	36	4.7	36	12.0	157.1
	4	18	5.5	18	11.1	105.3
	All	132	4.5	132	12.1	168.3
80 Basal Area Level	1	36	3.9	36	12.8	226.2
	2	36	4.2	36	12.4	191.5
	3	36	4.2	36	12.4	193.2
	4	24	4.6	24	12.1	164.3
	All	156	4.2	156	12.4	192.6
30 Basal Area Level	1	36	3.3	36	13.4	311.3
	2	36	4.0	36	12.7	220.6
	3	36	4.2	36	12.5	196.1
	4	24	4.8	24	11.8	145.7
	All	150	4.1	150	12.6	208.0

ANNUAL GROWTH OF UNTHINNED PONDEROSA PINE DURING TWO TIME PERIODS

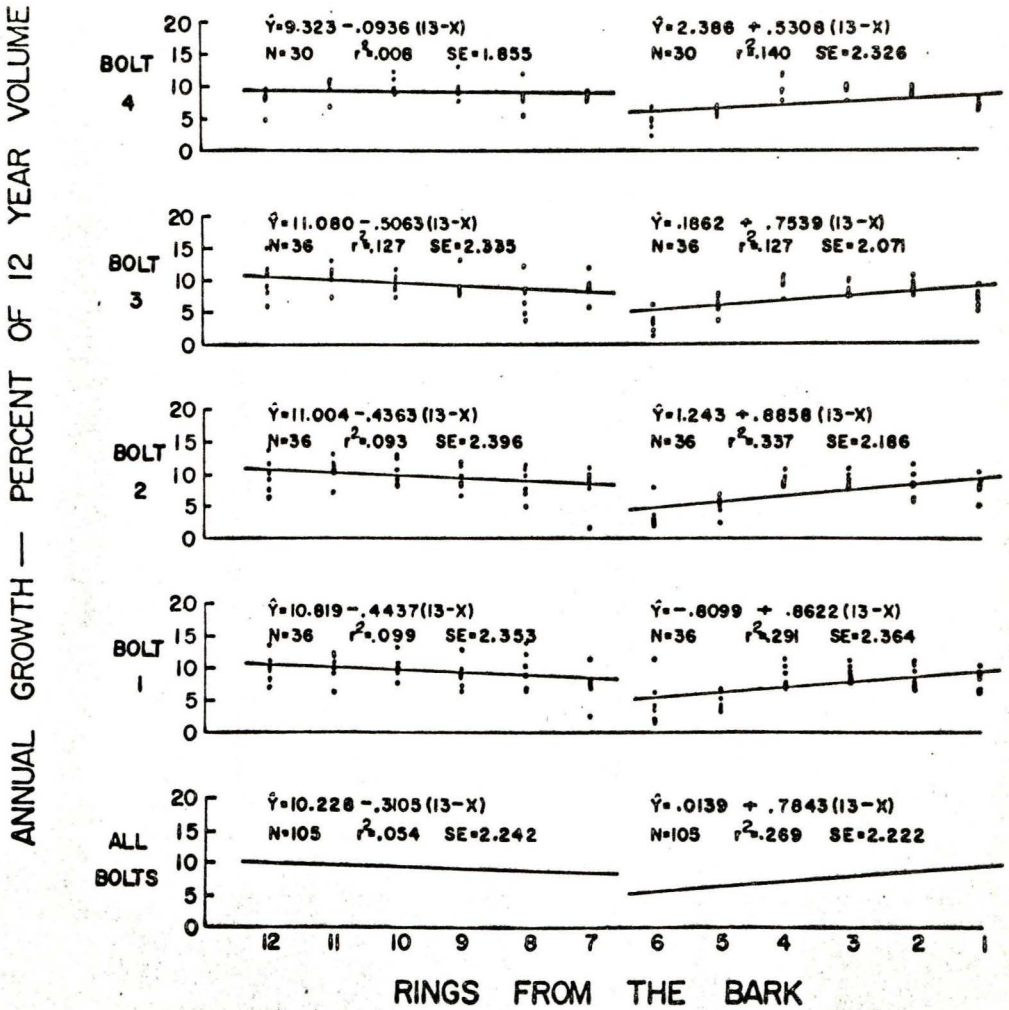

Figure 11

ANNUAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 150 BASAL AREA LEVEL

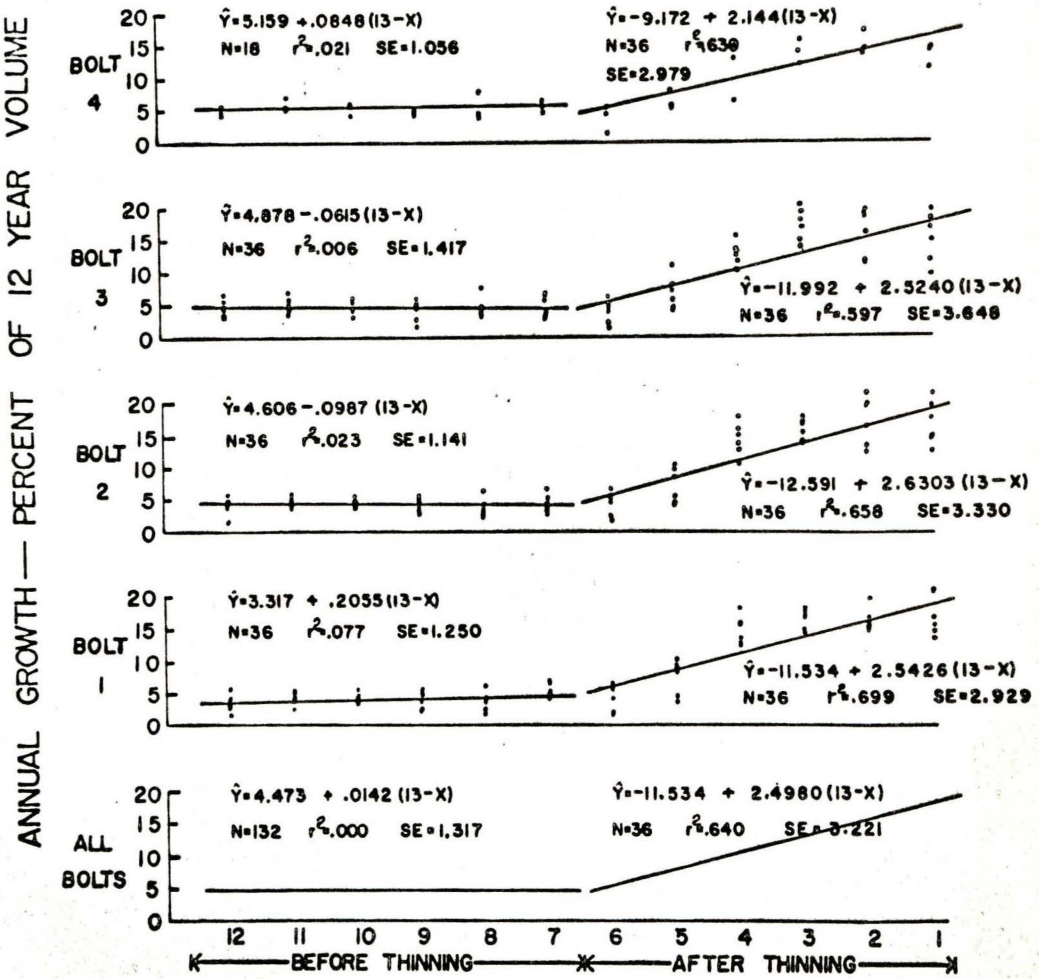

Figure 12

ANNUAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 80 BASAL AREA LEVEL

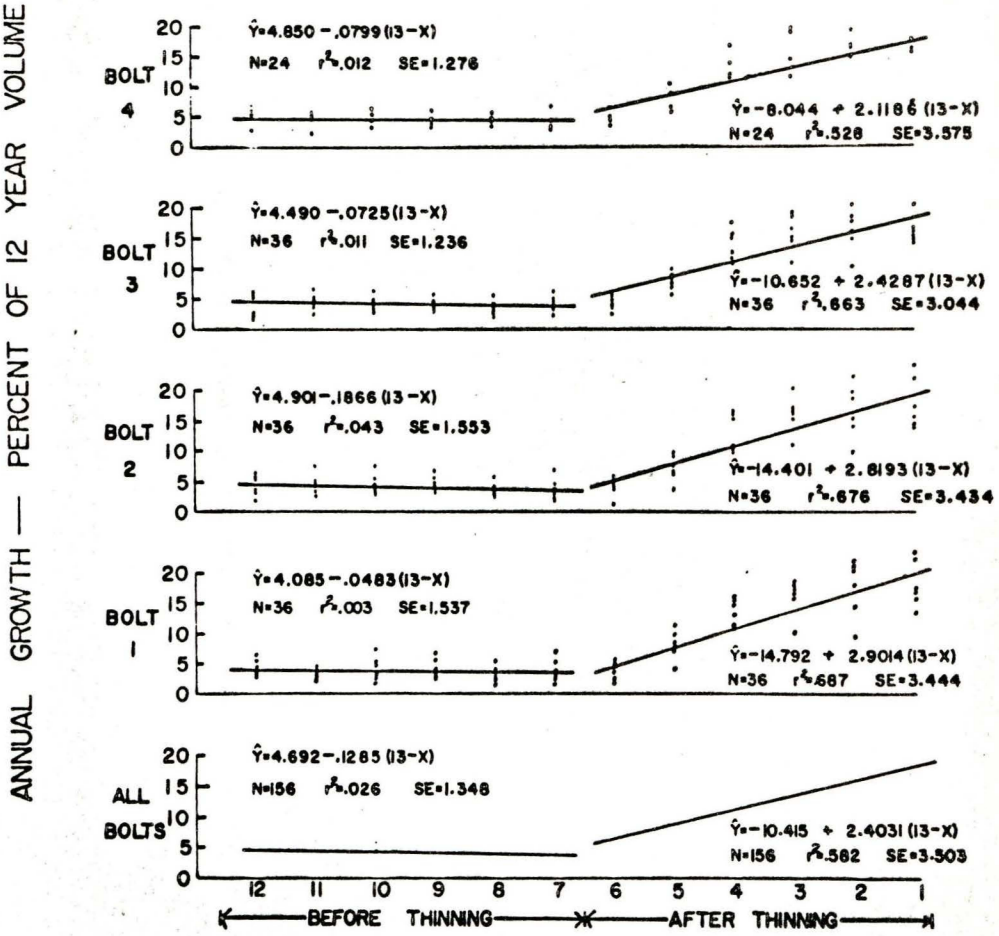

Figure 13

ANNUAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 30 BASAL AREA LEVEL

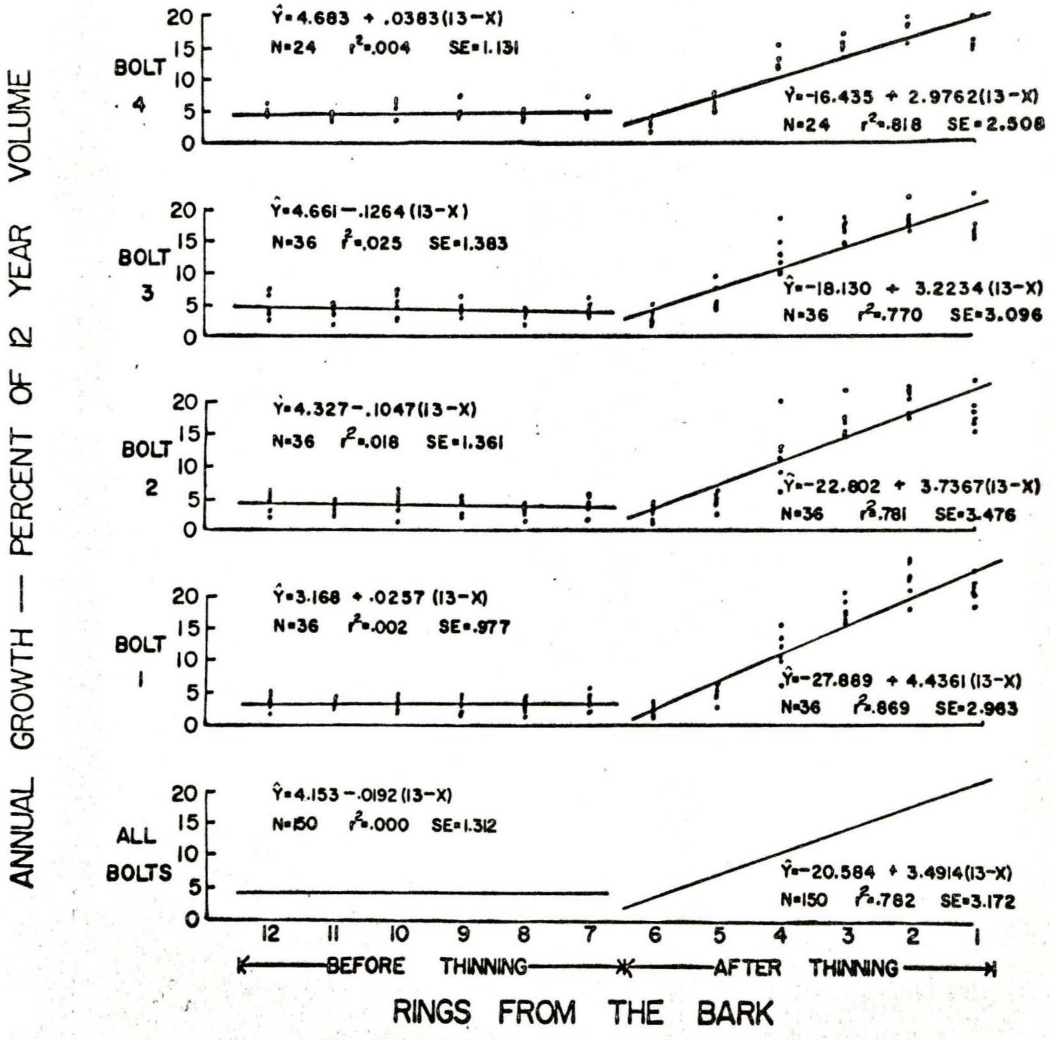

Figure 14

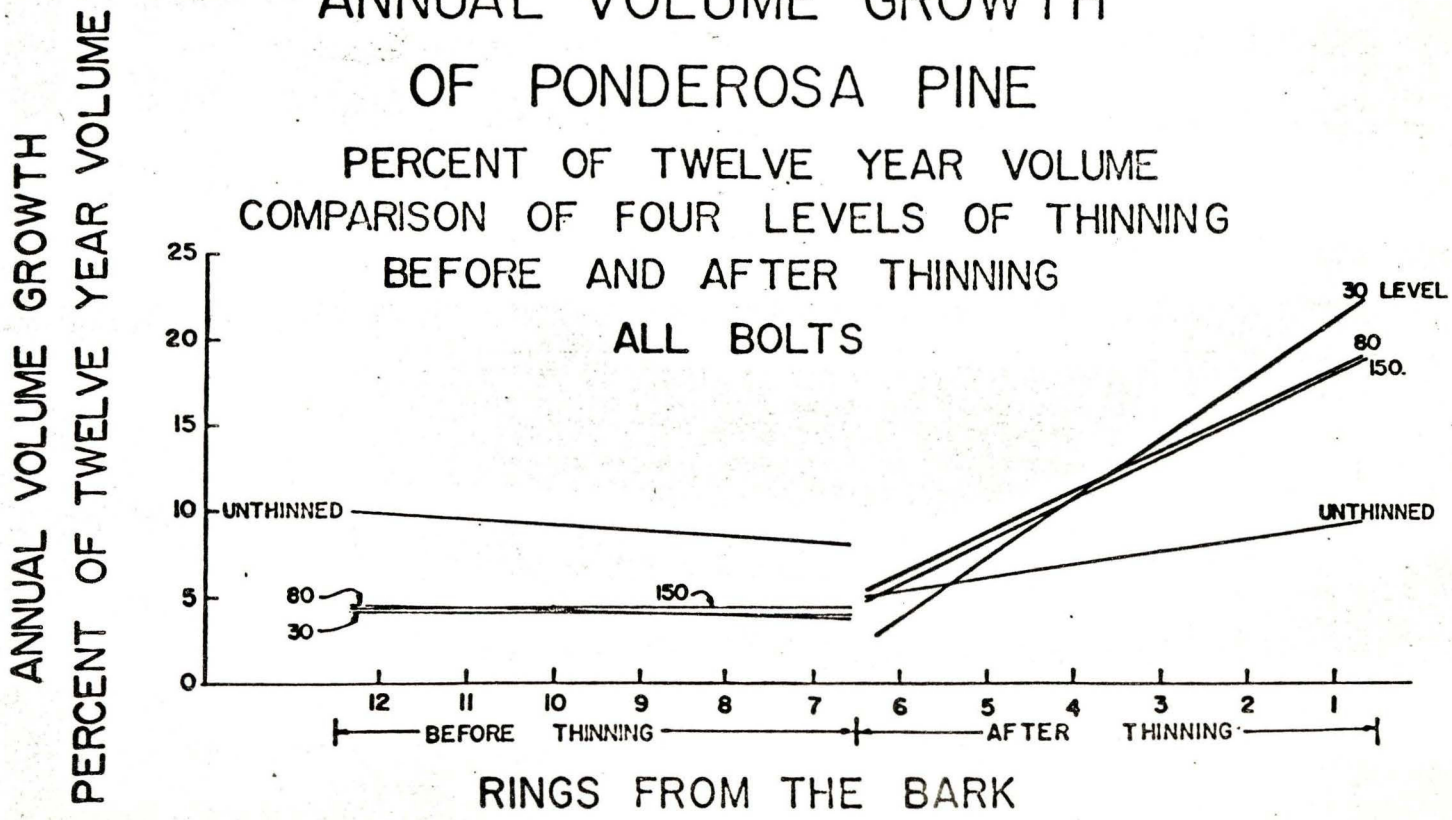
ANNUAL VOLUME GROWTH
OF PONDEROSA PINE
PERCENT OF TWELVE YEAR VOLUME
COMPARISON OF FOUR LEVELS OF THINNING
BEFORE AND AFTER THINNING
ALL BOLTS
ANNUAL VOLUME GROWTH
PERCENT OF TWELVE YEAR VOLUME
25
20
15
10
5
0
UNTHINNED
80
30
150
30 LEVEL
80
150.
UNTHINNED
12
11
10
9
8
7
6
5
4
3
2
1
BEFORE THINNING
AFTER THINNING
RINGS FROM THE BARK

Figure 15

TABLE IV

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF PER CENT LATEWOOD VOLUME BY HEIGHTS OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt No.	Rings 7-12 N	Rings 7-12 Mean %	Rings 1-6 N	Rings 1-6 Mean %	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	1	36	20.4	36	24.6	20.9	70	2.10	2.031*
	2	36	17.6	36	21.5	21.7	70	1.81	2.117*
	3	36	16.2	36	19.6	20.5	70	1.77	1.881*
	4	30	14.1	30	16.4	16.2	58	1.41	1.624NS
	All	150	16.8	150	20.2	19.8	298	.90	3.697**
150 Basal Area Level	1	36	23.3	36	16.7	-28.6	70	1.70	3.943**
	2	36	20.6	36	16.3	-21.0	70	1.70	2.547**
	3	36	19.0	36	16.0	-15.9	70	1.67	1.803*
	4	18	15.4	18	15.8	2.6	34	1.88	0.210NS
	All	132	19.8	132	16.2	-18.3	262	.88	4.116**
80 Basal Area Level	1	36	21.0	36	17.4	-17.1	70	1.75	2.051*
	2	36	19.2	36	18.9	-2.0	70	1.73	0.228NS
	3	36	16.7	36	15.4	-8.0	70	1.16	1.150NS
	4	24	14.3	24	14.9	4.7	46	1.27	0.525NS
	All	156	17.3	156	16.3	-6.0	310	.73	1.405NS
30 Basal Area Level	1	36	22.1	36	19.9	-10.1	64	1.86	1.207NS
	2	36	19.5	36	18.4	-5.9	70	1.82	0.627NS
	3	36	17.7	36	18.1	2.5	70	1.75	0.255NS
	4	24	16.4	24	18.2	10.7	46	2.52	0.701NS
	All	150	18.6	150	18.4	-1.3	289	.94	0.264NS

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE V

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF EARLYWOOD VOLUME OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt No.	Rings 7-12 N	Rings 7-12 Mean Cu.In.	Rings 1-6 N	Rings 1-6 Mean Cu.In.	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	All	150	33.0	150	26.4	-20.1	298	1.94	3.419**
150 Basal Area Level	All	132	14.7	132	39.8	170.4	163	2.12	11.858**
80 Basal Area Level	All	156	27.6	156	84.2	204.9	173	4.24	13.343**
30 Basal Area Level	All	150	26.2	150	80.7	207.5	164	4.37	12.466**

** - Significant at the 1% level

TABLE VI

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF LATEWOOD VOLUME OF DIFFERENT TREATMENT LEVELS

Treatment Level	Bolt No.	Rings 7-12 N	Rings 7-12 Mean Cu.In.	Rings 1-6 N	Rings 1-6 Mean Cu.In.	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	All	150	5.8	150	5.7	-1.6	298	.35	0.259NS
150 Basal Area Level	All	132	3.3	132	6.5	97.3	214	.37	8.752**
80 Basal Area Level	All	156	5.4	156	14.6	168.9	177	.77	11.925**
30 Basal Area Level	All	150	6.3	150	15.6	146.6	203	.98	9.427**

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

cent latewood volume that are reported in the following section.

Per Cent Latewood Volume

the unthinned trees showed a significant increase over the before treatment period, in per cent latewood volume for each bolt except the fourth. There was a significant decrease in the first, second and third bolts and all bolts combined and no significant difference in the fourth bolt of the 150 basal area level. In the 80 level there was a significant decrease in the first bolt and no difference in the rest of the bolts or all combined. There was no significant difference between before and after thinning in per cent latewood volume for the 30 basal area level (Table IV). (Due to the broad range of values, per cent latewood volume was tested with the standard tests used in this report.)

Analysis of variance of per cent latewood volume between bolts of the unthinned trees showed significant differences between bolts one and three and one and four during the pretreatment period and no significant difference between adjacent (those sharing a common end) bolts but significant differences between other combinations during the after treatment period (Appendix Tables XLI and XLII). The pretreatment period of all the thinning levels

show no significant difference between paired bolts and significant differences between unpaired bolts except in the pre-30 basal area level there was no difference between bolts two and four. During the after treatment period in all thinning levels there was no significant difference between any bolts (Appendix Tables XLIII-XLVIII).

The pretreatment data showed significant differences between the control and 150 and 30 levels and between the 150 level and 80 level and no significant differences between other comparisons. Thinning changed this to significant differences between the control and all thinning levels and significant differences between thinning levels except there was no significant difference between the 150 level and 80 level (Appendix Tables XLIX and L).

Unthinned trees increased in per cent latewood volume while thinning tended to decrease per cent latewood volume, although in most cases this decrease was not significant. Four out of the five cases where the decrease was observed as being significant were in the 150 basal area level. The unthinned trees tended to decrease, in per cent latewood volume, up the trees while the thinned trees showed no difference between bolts. Except for one case, there were significant differences between levels after thinning.

Per Cent Latewood Volume--Annual Volume Relationship

In general, thinning seemed to reduce the correlation between per cent latewood volume and annual volume, however the control data also declined in correlation from the before to the after thinning period. Even though there was a decline in correlation, only five of the forty comparisons made were not significant (two during the pretreatment period and three during the after thinning period) (Figures 16-19, Appendix Table XIV).

Volume Growth Summary

Accumulated volume growth on a per tree basis, expressed as a per cent increase over the pre-thinning period, increases with decreasing stand density with a higher per cent of increase higher in the tree. The unthinned trees showed a decrease in average annual volume growth during the after thinning period when compared with the pre-thinning period while thinning produced an increase in all thinned trees with the per cent response decreasing with increasing height. There were differences between the unthinned and thinned levels and differences between the 150 basal area level and both the 30 and 80 basal area levels but there was no difference between the 30 and 80 basal areas levels. The annual volume growth during the thinned period, expressed as a per cent of the twelve year

PERCENT LATEWOOD VOLUME – ANNUAL VOLUME RELATIONSHIP AT FOUR HEIGHTS IN UNTHINNED PONDEROSA PINE DURING TWO TIME PERIODS

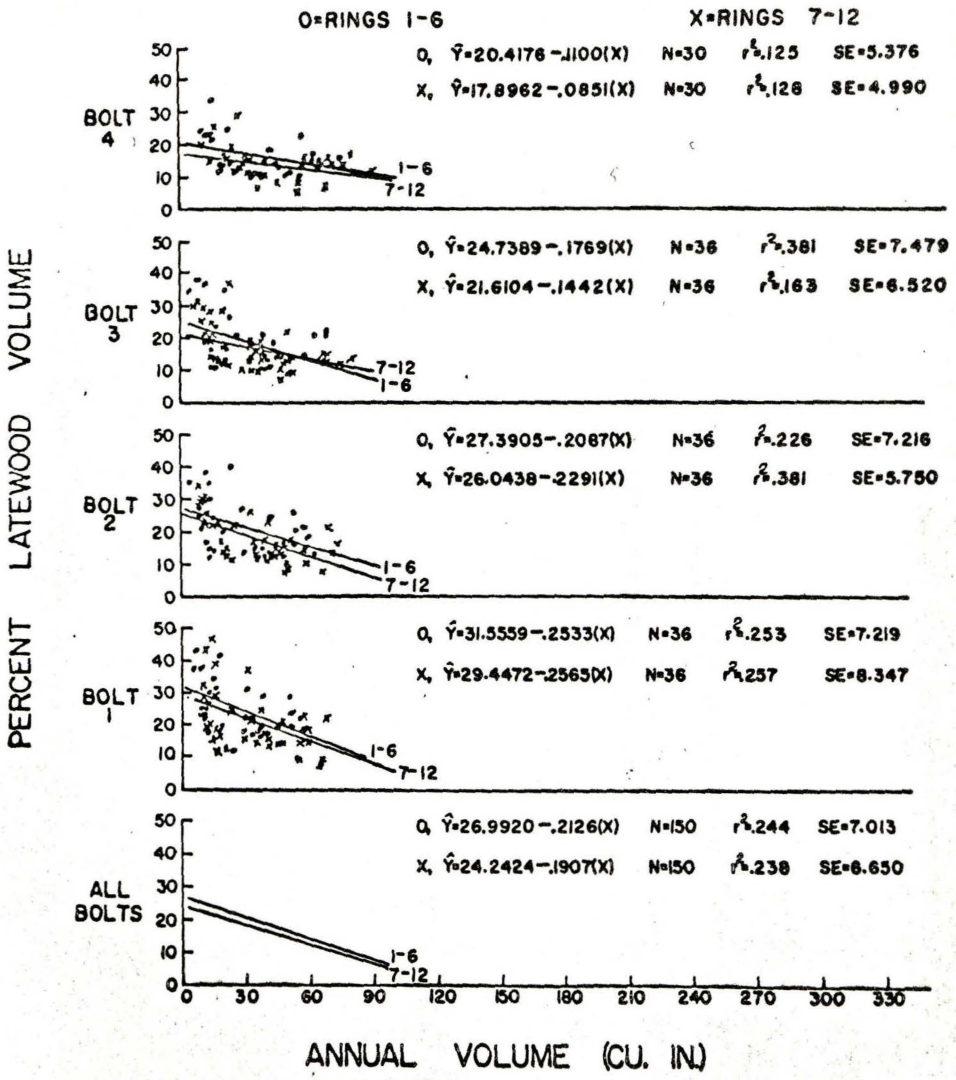

Figure 16

PERCENT LATEWOOD VOLUME - ANNUAL VOLUME RELATIONSHIP AT FOUR HEIGHTS IN PONDEROSA PINE BEFORE AND AFTER THINNING TO 150 BASAL AREA LEVEL

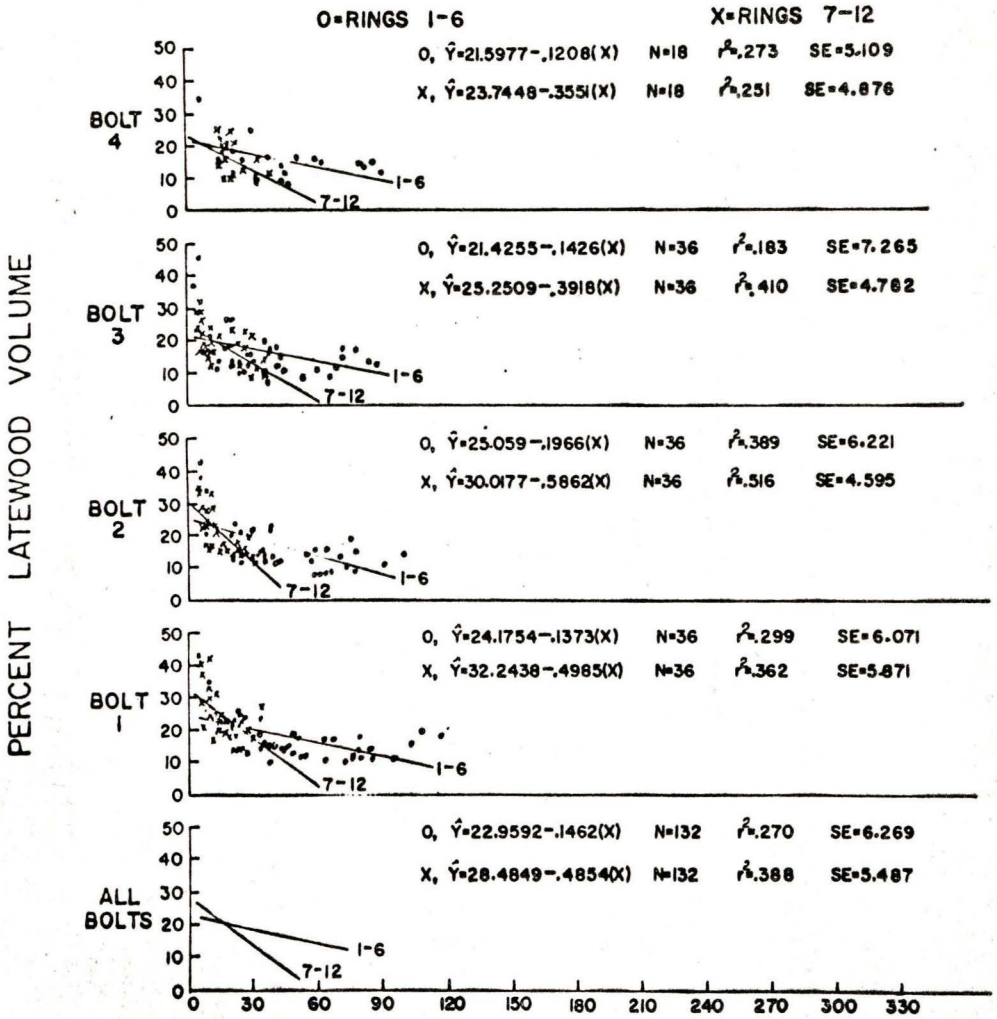

Figure 17

PERCENT LATEWOOD VOLUME - ANNUAL VOLUME RELATIONSHIP AT FOUR HEIGHTS IN PONDEROSA PINE BEFORE AND AFTER THINNING TO 80 BASAL AREA LEVEL

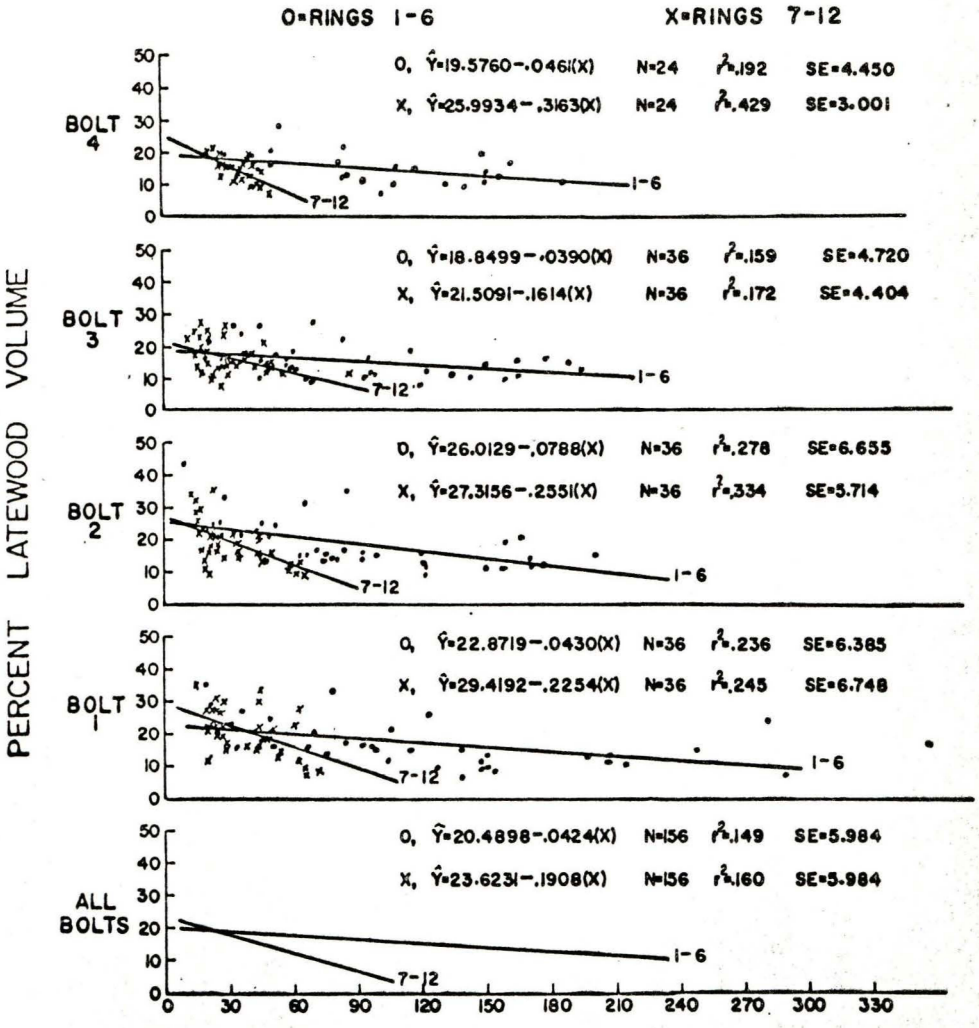

Figure 18

PERCENT LATEWOOD VOLUME — ANNUAL VOLUME RELATIONSHIP AT FOUR HEIGHTS IN PONDEROSA PINE BEFORE AND AFTER THINNING TO 30 BASAL AREA LEVEL

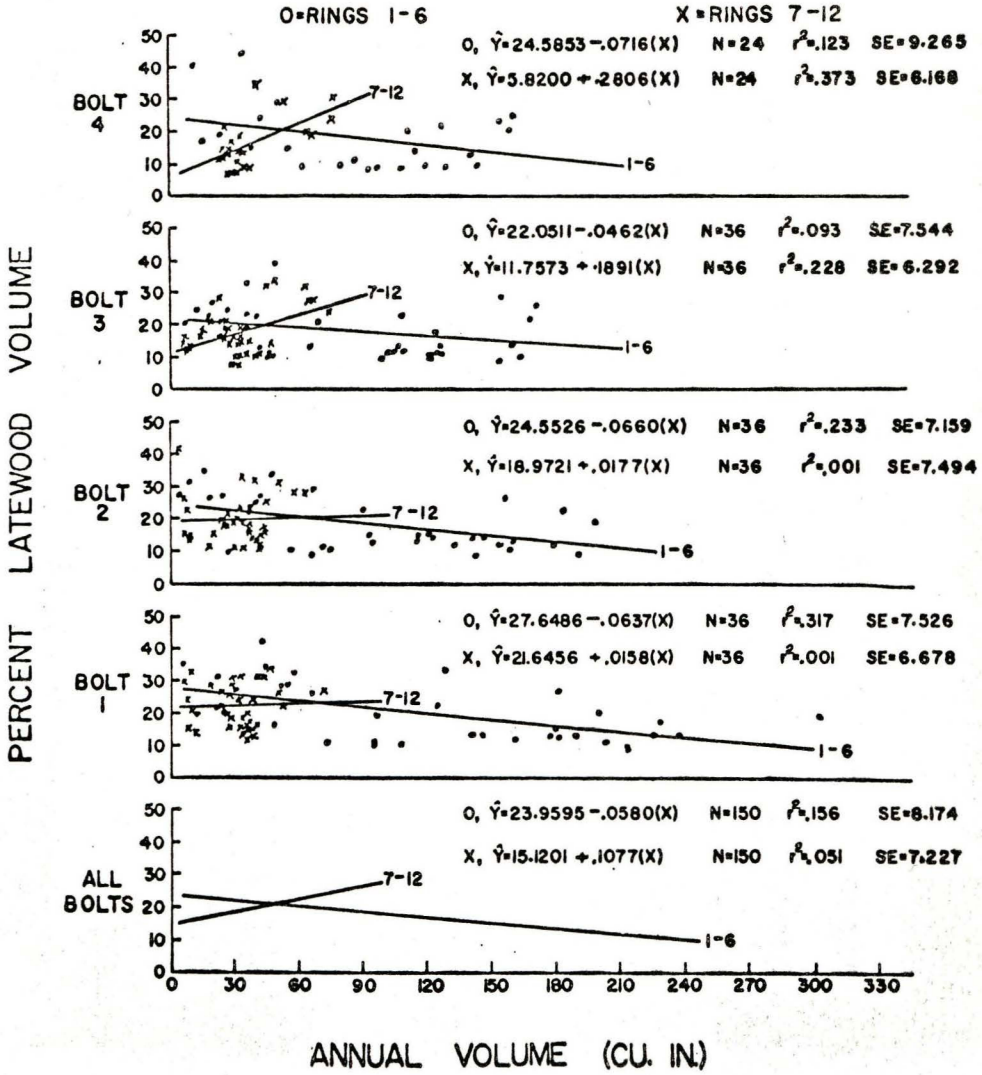

Figure 19

volume, decreased with increasing basal area but showed no differences between bolts. There were significant differences between the unthinned and thinned levels but no differences between thinned levels. Thus, at least on a per tree basis, it can be said that thinning increases volume growth in ponderosa pine. These results have previously been found by many authors. A few of those authors are Lowery and Schmidt (1967), Zahner (1958), Paul (1957, 1963), Paul and Smith (1956), Smith (1968) and, in ponderosa pine, Krauch (1924), Schubert and Martin (1969) and Paul and Meagher (1949).

If volume growth was to be put on a per acre basis there were 127 trees per acre left after thinning on the 30 basal area level plots, 325 on the 80 level plots and 688 on the 150 level plots. If the number of trees per acre is multiplied by the mean accumulated volume growth per bolt per tree for each level and then that result multiplied by the average number of bolts per tree it would give the accumulated volume growth per acre for each thinning level. The results are as follows:

Thinning Level	No. Trees per acre	Acc. Vol growth per Bolt (cu.in.)	Acc. Vol growth per Bolt per acre (cu.in.)	Ave. No. Bolts per Tree	Acc. Vol. growth per acre	
					cu.in. 6 yr. period	cu.ft. 6 yr. period
30	127	346	43,942	4.17	183,238	106.04
80	325	366	118,950	4.33	515,054	298.06
150	688	180	123,840	3.67	454,493	263.02

In comparing the 80 and 150 basal area levels of thinning, there is little difference. The 30 basal area level however, shows 65 per cent less accumulated volume per acre than the other thinning levels. This indicates that the 30 basal area level is not fully utilizing the site. For these stated conditions the forest manager who wants the greatest accumulated growth per acre with the shortest rotation would want to use the 80 basal area level in his thinning program.

II. SPECIFIC GRAVITY

The specific gravity values used, in the following analysis, were computed on the basis of green volume and oven dry weight after extraction with hot water and with an ethanol-benezine solution. The sample consisted of six ring segments, six rings before and six rings after thinning, taken at five foot intervals up the tree. Rings 1-6 of the control trees showed a general increase in specific gravity when compared with rings 7-12. However, only the increase at five feet was significant. All the thinning levels showed decreases in specific gravity for the same time period, but only at 20 feet in the 150 basal area data was the decrease significant (Table VII).

TABLE VII

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF SPECIFIC GRAVITY OF DIFFERENT THINNING LEVELS

Treatment Level	Ht.	Rings 7-12 N	Rings 7-12 Mean Sp.Gr.	Rings 1-6 N	Rings 1-6 Mean Sp.Gr.	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	Base	6	.390	6	.414	6.15	10	.017	1.384NS
	5'	6	.357	6	.386	8.22	10	.013	2.311*
	10'	6	.341	6	.348	2.15	10	.017	0.440NS
	15'	6	.321	6	.328	2.02	10	.008	0.830NS
	20'	5	.335	5	.325	-2.87	8	.009	1.101NS
	All	31	.349	31	.360	3.29	60	.009	1.258NS
150 Basal Area Level	Base	6	.418	6	.405	-3.07	10	.019	0.691NS
	5'	6	.369	6	.364	-1.49	10	.015	0.365NS
	10'	6	.344	6	.342	-0.58	10	.016	0.123NS
	15'	6	.347	6	.329	-5.28	10	.013	1.370NS
	20'	4	.356	4	.315	-11.65	6	.009	4.579**
	All	29	.367	29	.353	-3.94	56	.010	1.448NS
80 Basal Area Level	Base	6	.379	6	.390	2.86	10	.024	0.449NS
	5'	6	.380	6	.359	-5.61	7	.019	1.116NS
	10'	6	.350	6	.343	-1.81	10	.015	0.423NS
	15'	6	.337	6	.324	-3.76	10	.010	1.211NS
	20'	5	.337	5	.316	-6.24	8	.014	1.518NS
	All	35	.351	35	.339	-3.46	68	.009	1.349NS
30 Basal Area Level	Base	6	.370	6	.374	.90	10	.013	0.250NS
	5'	6	.358	6	.345	-3.45	10	.008	1.455NS
	10'	6	.343	6	.328	-4.14	10	.009	1.580NS
	15'	6	.330	6	.317	-3.74	10	.008	1.568NS
	20'	5	.319	5	.312	-2.13	8	.008	0.891NS
	All	33	.341	33	.331	-2.94	64	.007	1.502NS

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

Thinning tended to increase the significant differences in specific gravity between heights, with most differences being between the lower and higher height. In general, there were no differences in specific gravity above ten feet in the tree. This trend was shown in all thinning levels (Appendix Tables LV-LXII).

Analysis of variance of specific gravity between treatment levels showed significant differences between the control and 150 basal area level and between the 150 level and both the 80 and 30 levels for the pretreatment data. The after thinning data showed significant differences between the control and both the 80 and 30 levels and between the 150 level and 30 level. All other comparisons showed no significant differences (Appendix Tables LXIII and LXIV).

In general, thinning tended to decrease specific gravity while that of the unthinned trees increased, however neither the increases nor decreases were significant. Significant differences in specific gravity between basal area levels that were not closely associated (unthinned-vs-80 and 30 levels) were evident, while no significant differences were found with thinning levels that were closely associated.

Correlations Between Specific Gravity and Tree Characteristics

The specific gravity of rings 1-6 increased with increasing basal area per acre (taken with a ten factor prism at time of sample). All external tree characteristics were measured at the same time the tree was sampled. The relationship of specific gravity to basal area per acre decreases with increasing height up the tree (Figure 20). However, only at the base, five feet and all heights pooled were the correlations significant (Appendix Table XV). When all heights were pooled, eight per cent of the variation in specific gravity was assoicated with basal area per acre while at the five foot height level 20 per cent was associated with basal area per acre.

The three measurements of live crown used in regression analysis (per cent, volume and surface area) showed specific gravity decreases with increasing crown size (Figures 21, 22, and 23). When specific gravity of all heights within a tree were pooled, 4.3 per cent of the variation in specific gravity was associated with per cent live crown, 3.8 per cent with crown volume and 3.7 per cent with crown surface area. All of these correlations were significant while no specific gravity measurements at individual heights were significant with either the crown surface area or crown volume when they were used as

SPECIFIC GRAVITY - BASAL AREA PER ACRE RELATIONSHIP IN PONDEROSA PINE BY HEIGHT LEVELS

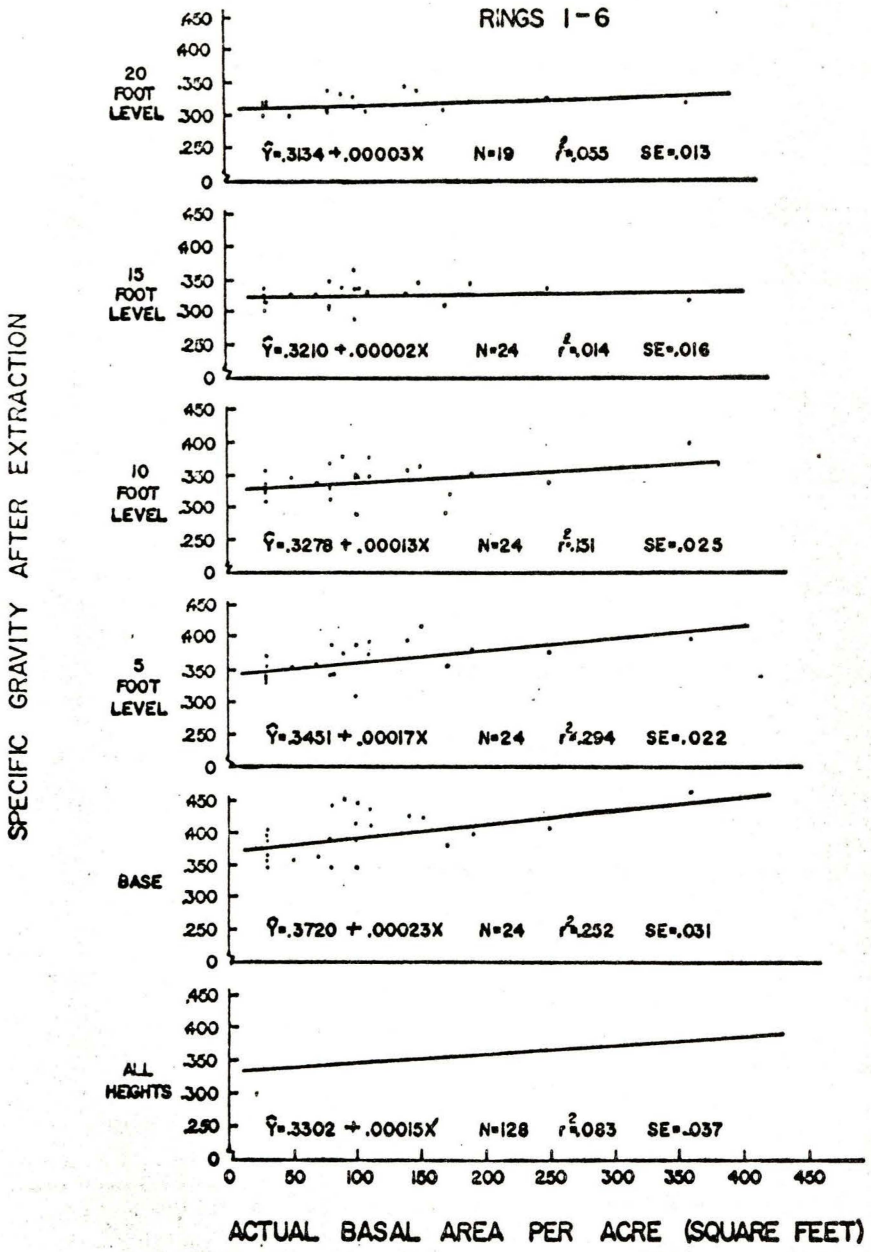

Figure 20

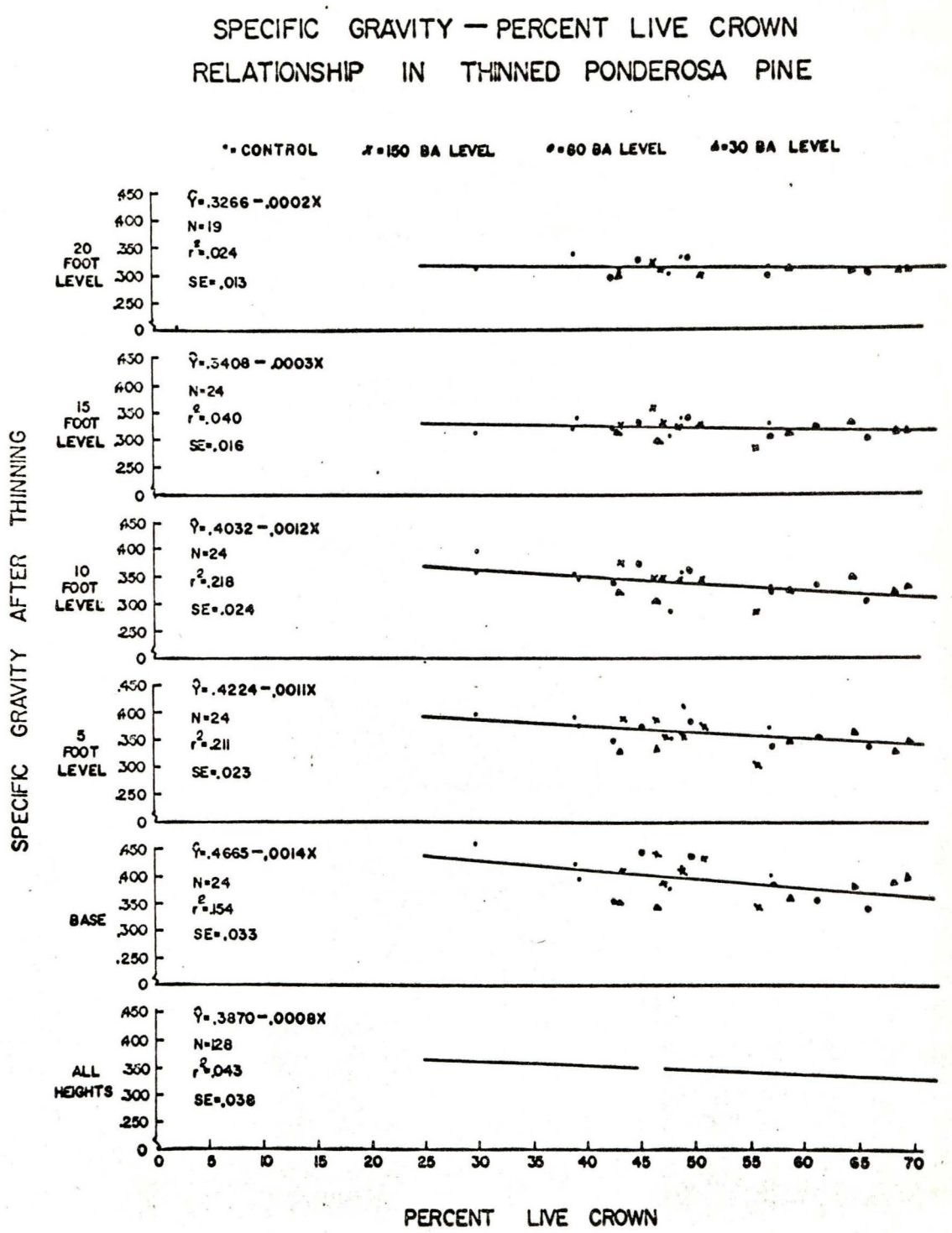
SPECIFIC GRAVITY — PERCENT LIVE CROWN
RELATIONSHIP IN THINNED PONDEROSA PINE
•= CONTROL
x=150 BA LEVEL
o=80 BA LEVEL
Δ=30 BA LEVEL
SPECIFIC GRAVITY AFTER THINNING
20 FOOT LEVEL
Ŷ=.3266−.0002X
N=19
r²=.024
SE=.013
15 FOOT LEVEL
Ŷ=.3408−.0003X
N=24
r²=.040
SE=.016
10 FOOT LEVEL
Ŷ=.4032−.0012X
N=24
r²=.218
SE=.024
5 FOOT LEVEL
Ŷ=.4224−.0011X
N=24
r²=.211
SE=.023
BASE
Ŷ=.4665−.0014X
N=24
r²=.154
SE=.033
ALL HEIGHTS
Ŷ=.3870−.0008X
N=128
r²=.043
SE=.038
PERCENT LIVE CROWN

Figure 21

SPECIFIC GRAVITY—LIVE CROWN VOLUME RELATIONSHIP IN THINNED PONDEROSA PINE

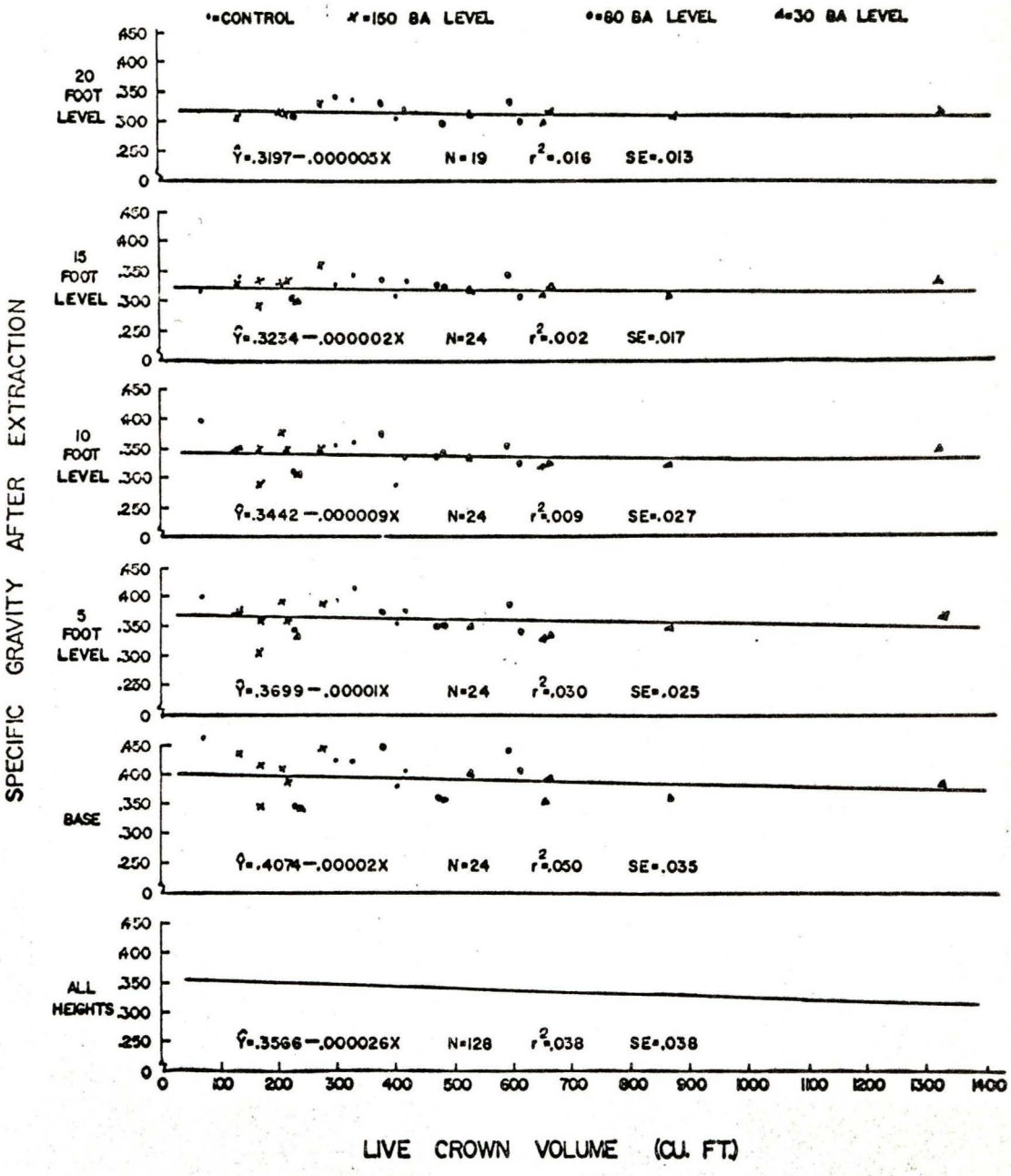

Figure 22

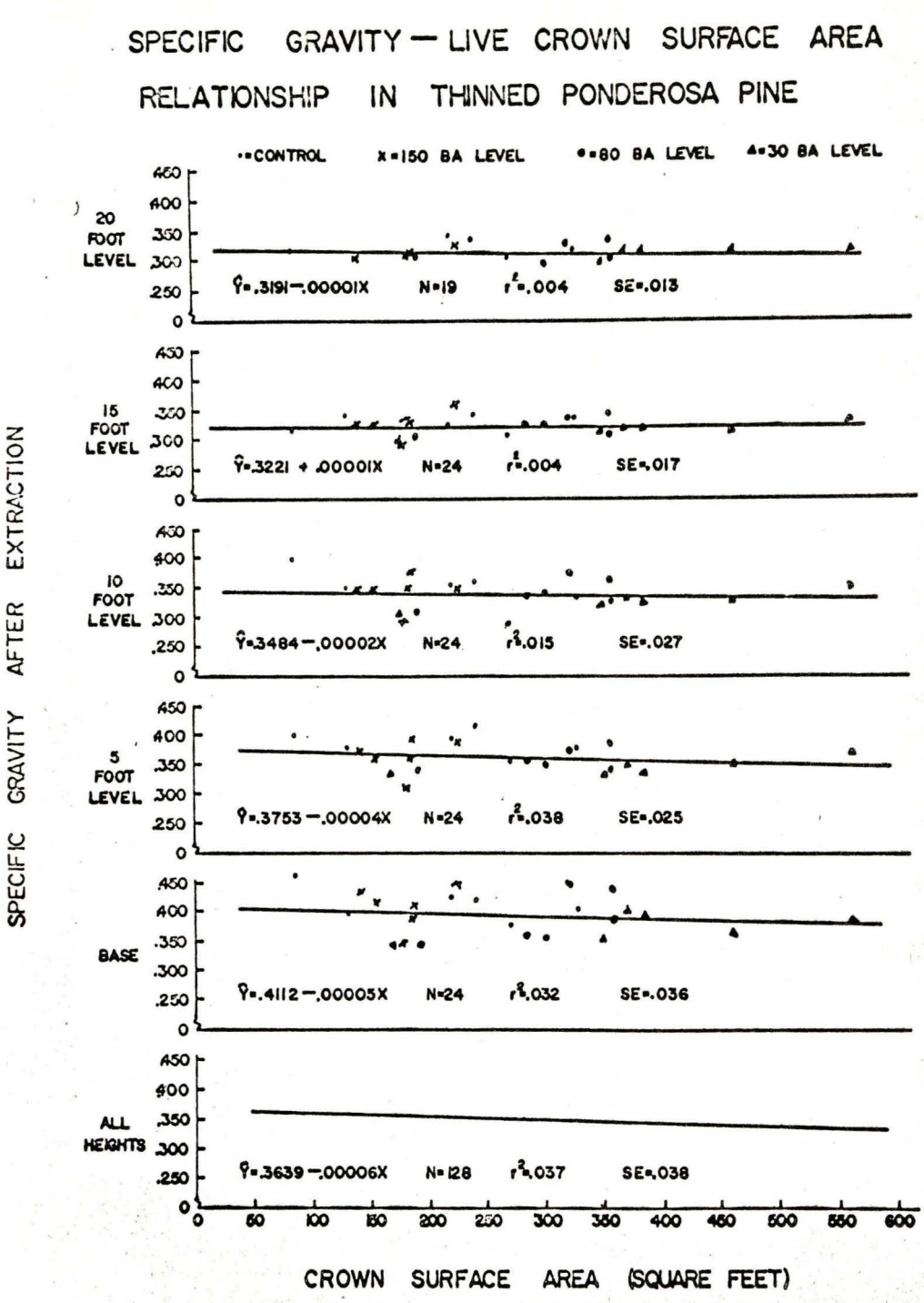
SPECIFIC GRAVITY — LIVE CROWN SURFACE AREA RELATIONSHIP IN THINNED PONDEROSA PINE
•=CONTROL x=150 BA LEVEL ●=80 BA LEVEL ▲=30 BA LEVEL
20 FOOT LEVEL
Ŷ=.3191−.00001X N=19 r²=.004 SE=.013
15 FOOT LEVEL
Ŷ=.3221 + .00001X N=24 r²=.004 SE=.017
10 FOOT LEVEL
Ŷ=.3484−.00002X N=24 r²=.015 SE=.027
5 FOOT LEVEL
Ŷ=.3753−.00004X N=24 r²=.038 SE=.025
BASE
Ŷ=.4112−.00005X N=24 r²=.032 SE=.036
ALL HEIGHTS
Ŷ=.3639−.00006X N=128 r²=.037 SE=.038
SPECIFIC GRAVITY AFTER EXTRACTION
CROWN SURFACE AREA (SQUARE FEET)

Figure 23

independent variables. However, correlations at five and ten feet were significant when per cent live crown was used, with both showing over 21 per cent of the variation in specific gravity being accounted for by per cent live crown (Appendix Table XV).

Specific gravity decreased with increasing height in all trees of this study, both before and after thinning. However, thinning improved the correlation. The correlation coefficients of all regressions, both before and after thinning, were significant. When all of the specific gravity values were pooled, height accounted for 38 percent of the variation in specific gravity for the pretreatment period and 56 percent during the after treatment period. (Appendix Table XVL, Figure 24)

Specific gravity decreased as the number of rings per inch decreased in all the pretreatment data as did the control and 150 basal area level for the after treatment data, while the 80 and 30 basal area level data for the after treatment period showed an increase in specific gravity as the number of rings per inch decreased (Figure 25, Appendix Table XVI).

Specific gravity showed varying relations with latewood width both before and after thinning, with only the 80 basal area level after thinning data, having a significant correlation (Figure 26, Appendix Table XVI).

SPECIFIC GRAVITY – HEIGHT RELATIONSHIP IN PONDEROSA PINE BEFORE (RINGS 7-12) AND AFTER (RINGS 1-6) THINNING TO FOUR BASAL AREA LEVELS

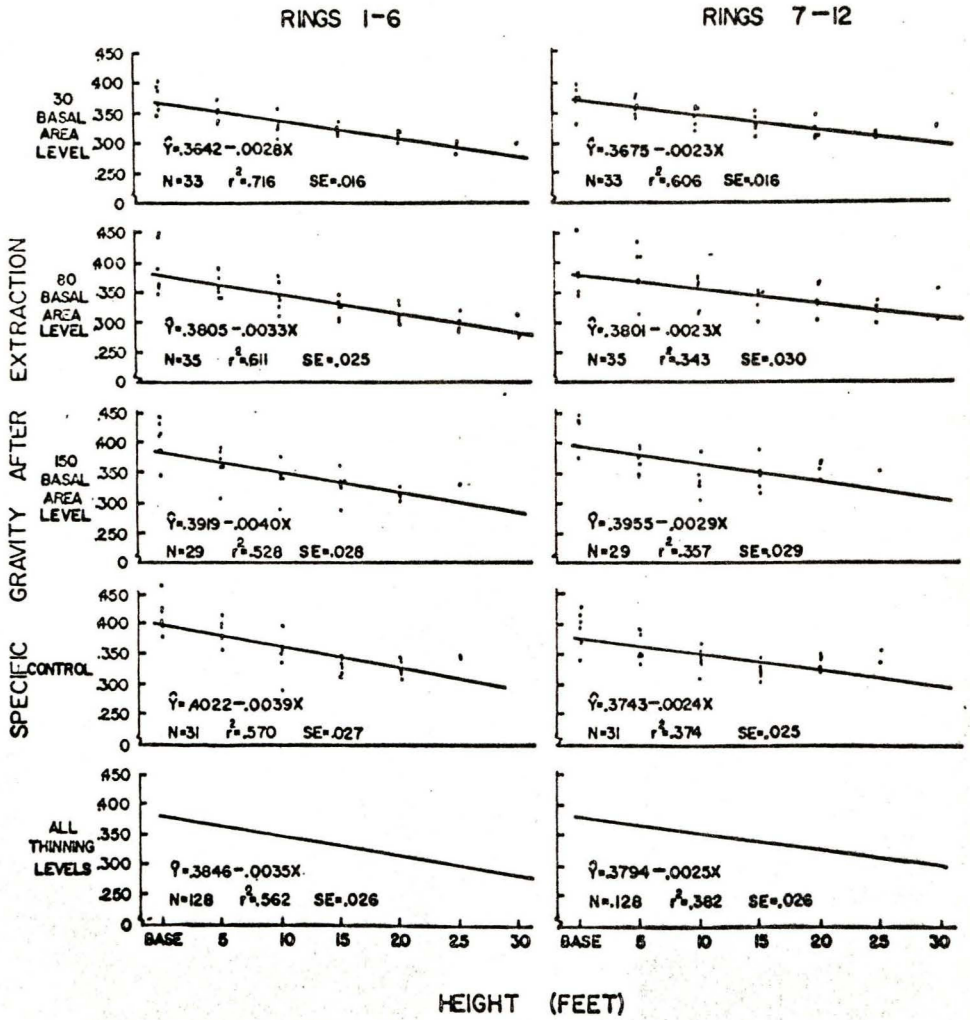

Figure 24

SPECIFIC GRAVITY — RINGS PER INCH RELATIONSHIP IN PONDEROSA PINE, BEFORE AND AFTER THINNING TO FOUR BASAL AREA LEVELS

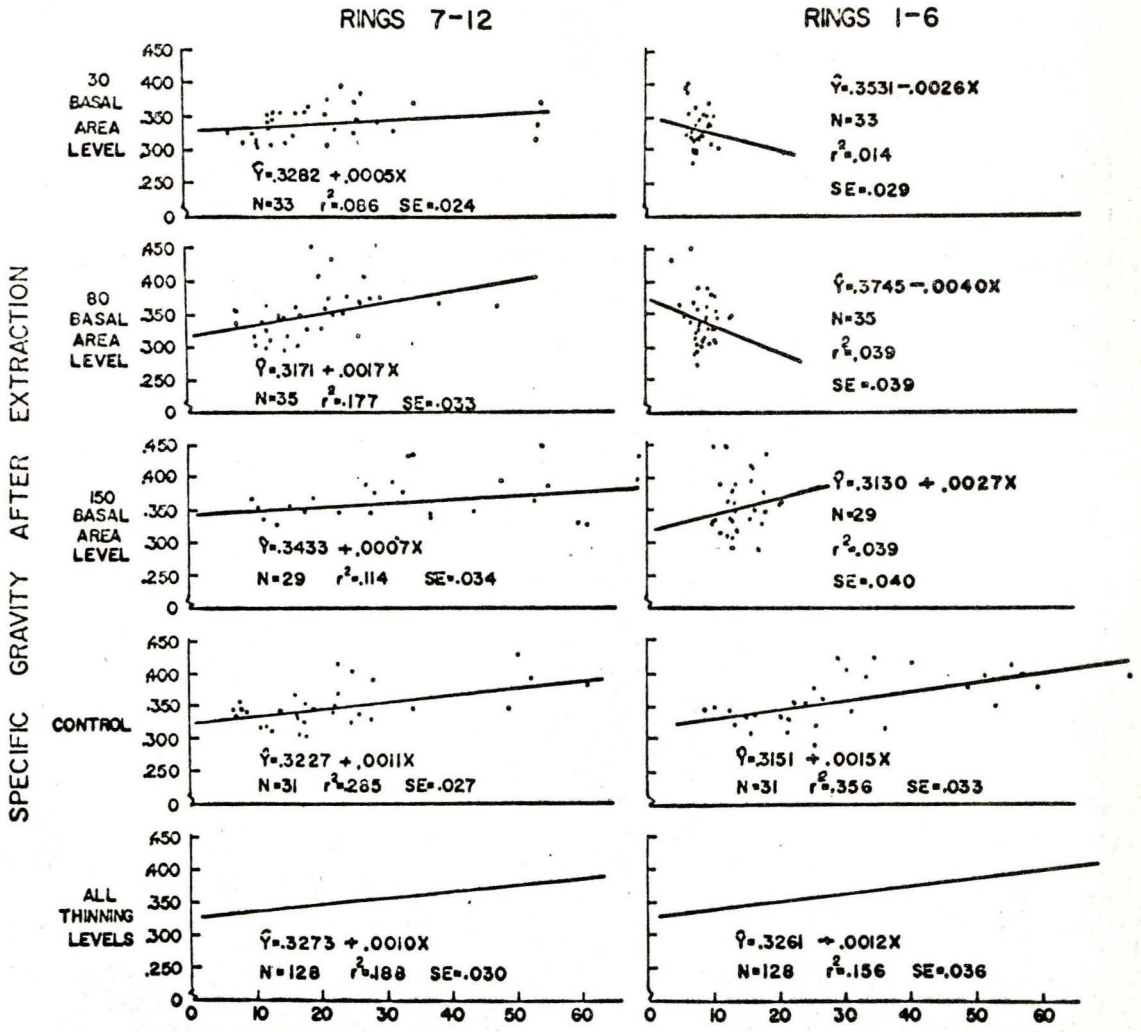

Figure 25

SPECIFIC GRAVITY – LATEWOOD WIDTH RELATIONSHIP IN PONDEROSA PINE, BEFORE AND AFTER THINNING TO FOUR BASAL AREA LEVELS

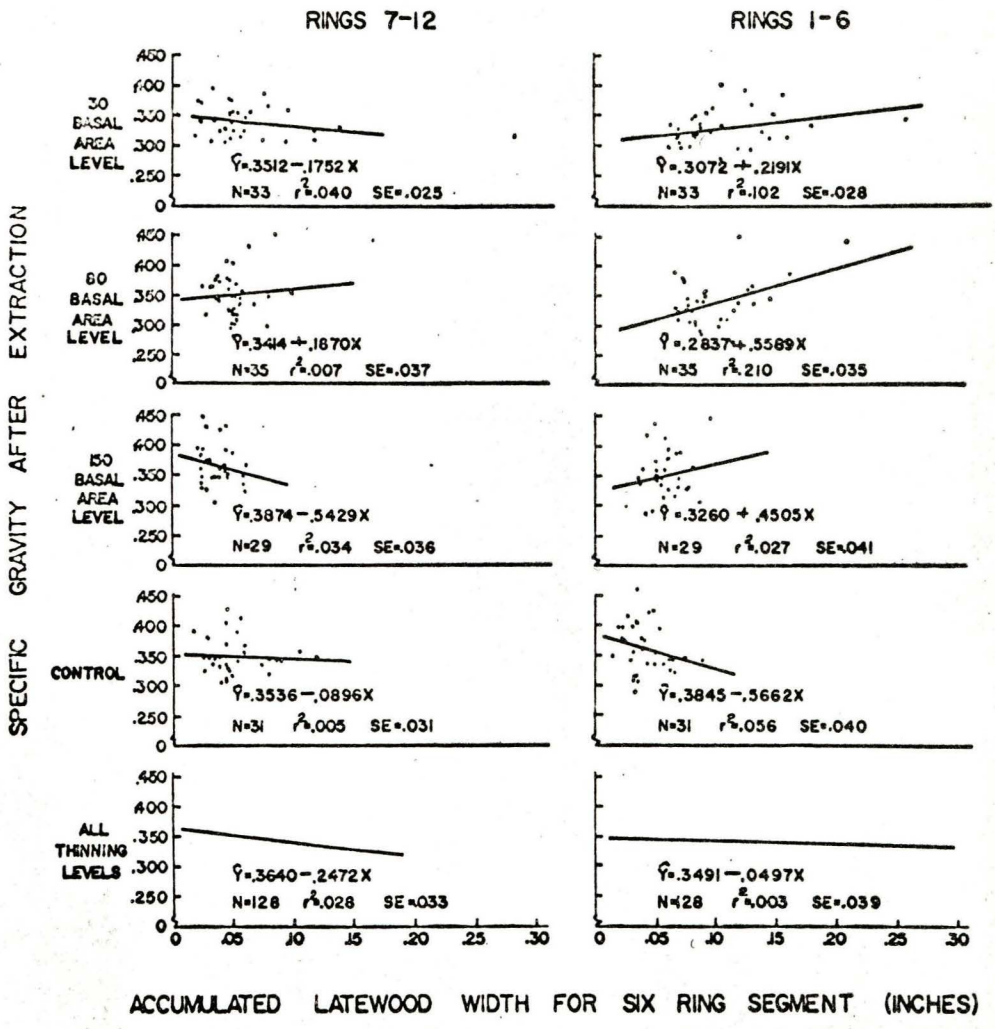

Figure 26

There was generally a negative relationship between specific gravity and width of the six ring segment, except in the after thinning data of the 30 and 80 basal area levels, where the relationships were positive. Only the 150 level correlation, before thinning, was not significant, while in both the 150 and 30 levels the correlation, after thinning, were not significant (Figure 27, Appendix Table XVI).

In general thinning caused a decrease in the correlation coefficient between specific gravity and per cent latewood, while the correlation increased in the control data. When the data for the unthinned and all the thinning levels were pooled, per cent latewood accounted for 29.5 per cent of the variation in specific gravity in rings 7-12 and 19.8 per cent in rings 1-6. All the relationships, for both before and after thinning, were positive, thus specific gravity increases with increasing per cent latewood (Figure 28, Appendix Table XVI).

The relationship between the specific gravity at the base of each bolt and per cent latewood volume of the bolt parallels that of per cent latewood except that in all cases the after thinning data showed better correlation with specific gravity than the before thinning data. When all the specific gravity values were pooled, per cent latewood volume accounted for 26.7 per cent of the

SPECIFIC GRAVITY – WIDTH OF SIX RING SEGMENT RELATIONSHIP IN PONDEROSA PINE, BEFORE AND AFTER THINNING TO FOUR BASAL AREA LEVELS

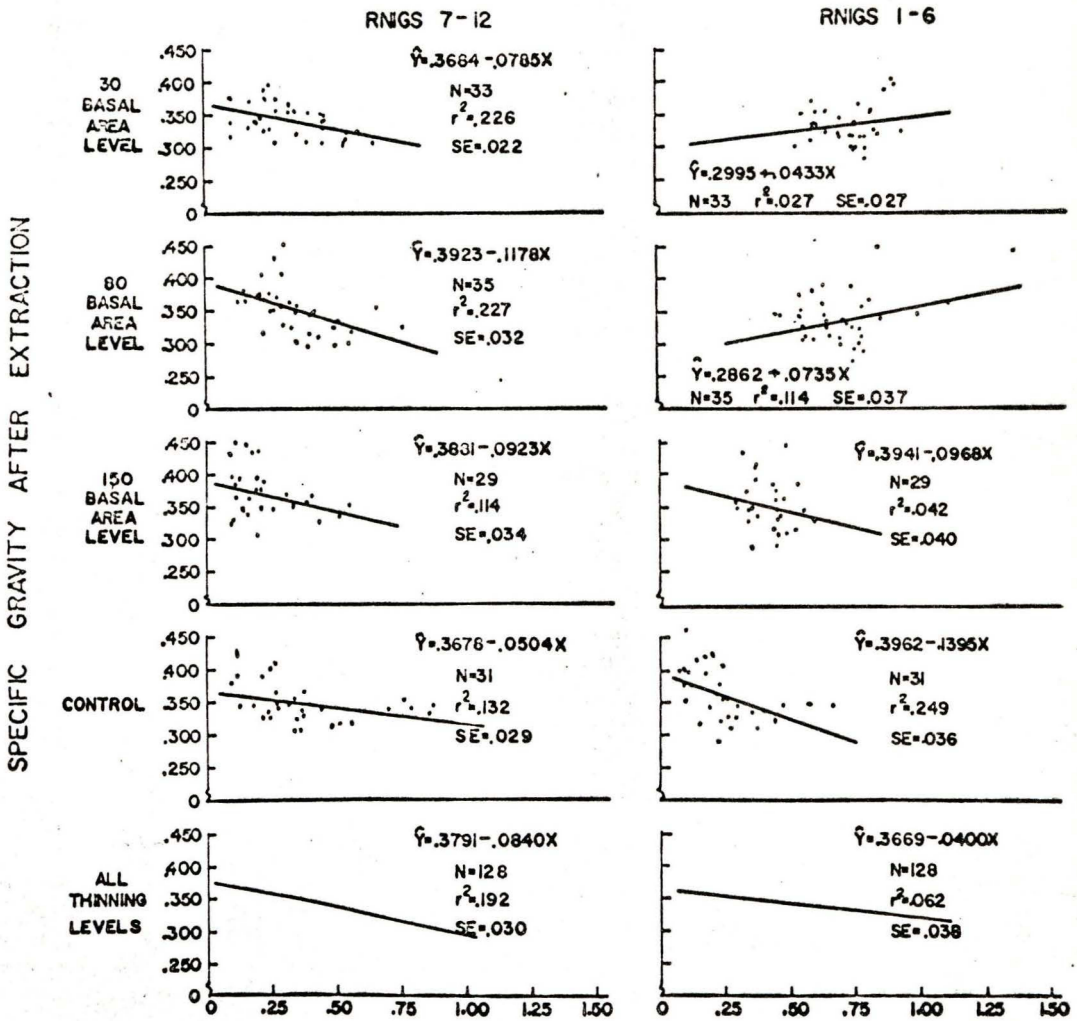

Figure 27

SPECIFIC GRAVITY — PERCENT LATEWOOD RELATIONSHIP IN PONDEROSA PINE BEFORE AND AFTER THINNING TO FOUR BASAL AREA LEVELS

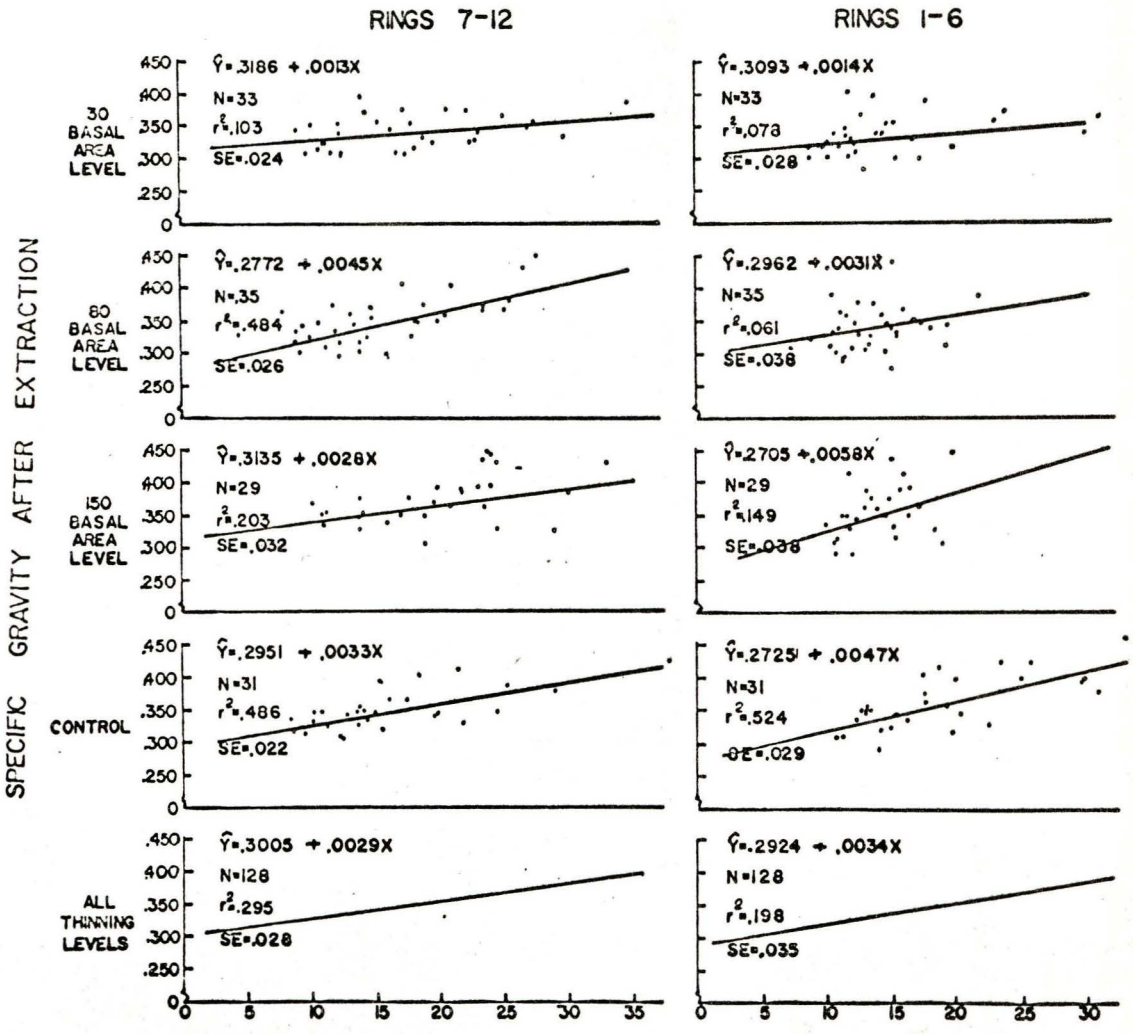

Figure 28

variation in specific gravity for rings 7-12 and 28.3 per cent for rings 1-6 (Figure 29, Appendix Table XVI).

Table VIII shows that in multiple regressions, the best four variables to use in predicting specific gravity for the before thinning data at each basal area level and for all levels pooled, using internal tree characteristics. Table IX shows the best four multiple regressions, using external tree characteristics, to predict specific gravity during the after thinning period. For the same period, Table X shows the best four multiple regressions, using both internal and external characteristics, that will predict specific gravity.

When all the before thinning data were pooled the best two variables, used in multiple regression analysis, were the height at which specific gravity was being predicted and per cent latewood. These two variables accounted for 44 per cent of the variation in specific gravity. The addition of either latewood width and/or rings per inch, as independent variables, produced very little, if any increase in the correlation with specific gravity (Table VIII).

When all data are pooled for the after thinning period the best four variables are external characteristics, even when internal tree characteristics are included.

SPECIFIC GRAVITY AT THE BASE OF EACH BOLT — PERCENT LATEWOOD VOLUME OF THAT BOLT RELATIONSHIP IN PONDEROSA PINE, BEFORE AND AFTER THINNING TO FOUR BASAL AREA LEVELS

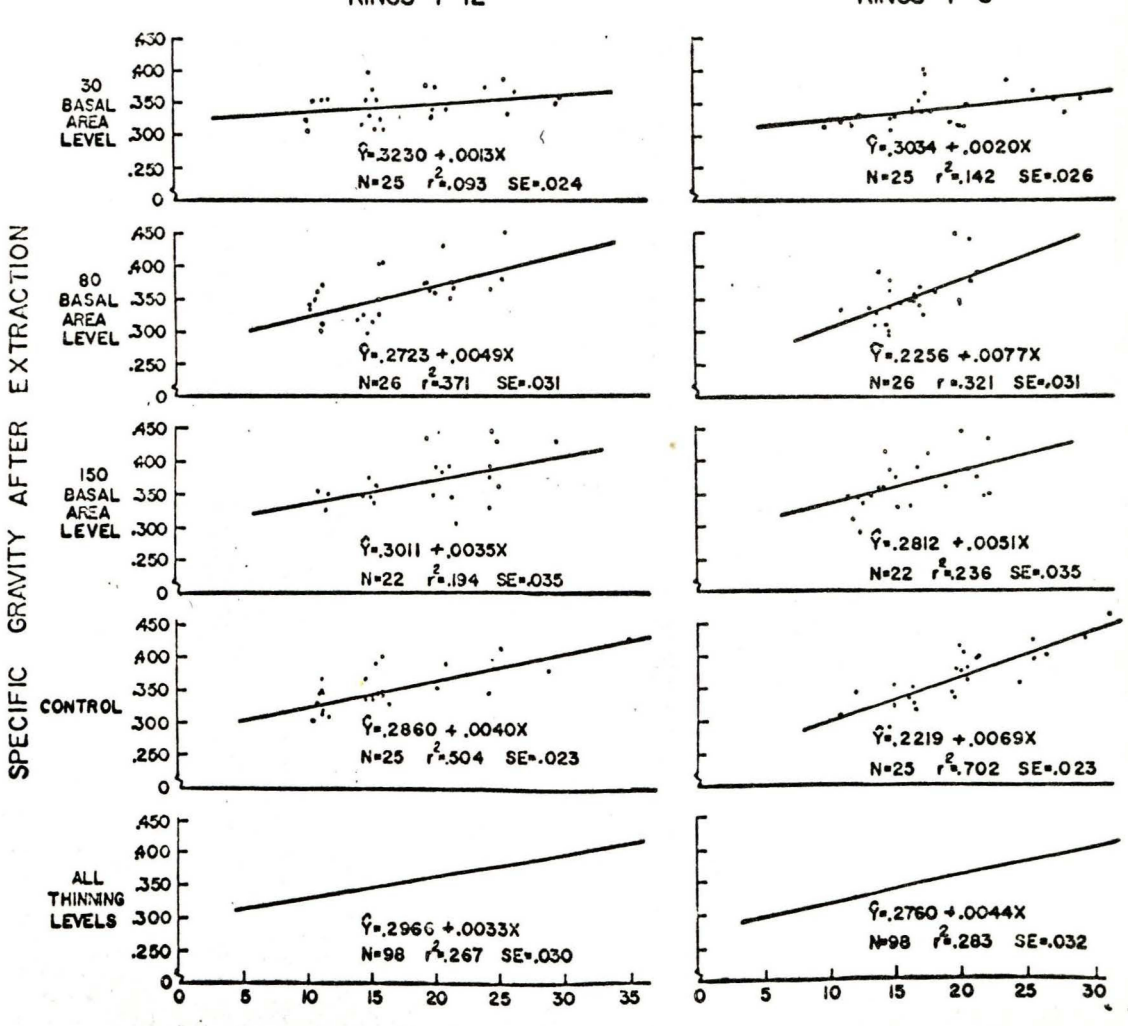

Figure 29

TABLE VIII

SIMPLE LINEAR REGRESSION EQUATIONS AND BEST MULTIPLE REGRESSION EQUATIONS FOR EXTIMATING SPECIFIC GRAVITY AFTER EXTRACTION DURING THE 6 YEARS BEFORE THINNING OF PONDEROSA PINE

Regression Equations	Correlation Coefficient
Control Trees	
Y=0.2950+0.0033(%LW)	0.6972
Y=0.3230-0.0013(Ht)+0.0025(%LW)	0.7574
Y=0.3000-0.0027(Ht)+0.0013(R/in)+0.9338(LW W)	0.8255
Y=0.3002-0.0025(Ht)+0.0010(R/in)+0.8069(LW W) +0.0007(%LW)	0.8288
150 Basal Area Level Trees	
Y=0.3955-0.0029(Ht)	0.5978
Y=0.3825-0.0032(Ht)+0.4458(LW W)	0.6121
Y=0.3331-0.0030(Ht)+0.0006(R/in)+1.110(LW W)	0.6366
Y=0.3295-0.0032(Ht)+0.0009(R/in)+1.354(LW W) -0.0007(%LW)	0.6379
80 Basal Area Level Trees	
Y= 0.2771+0.0045(%LW)	0.6956
Y=0.3048-0.0009(Ht)+0.0035(%LW)	0.7181
Y=0.3333-0.0032(R/in)-1.177(LW W)+0.0087(%LW)	0.7445
Y=0.3449-0.0008(Ht)-0.0028(R/in)-0.0133(LW W) +0.0074(%LW)	0.7569
30 Basal Area Level Trees	
Y=0.3674-0.0023(Ht)	0.7782
Y=0.3875-0.0028(Ht)-0.0006(R/in)	0.8152
Y=0.3852-0.0033(Ht)+0.3796(LW W)-0.0016(%LW)	0.8198
Y=0.3893-0.0032(Ht)-0.0003(R/in)+0.2510(LW W) +0.0011(%LW)	0.8223
All Trees Pooled	
Y=0.3793-0.0025(Ht)	0.6178
Y=0.3448-0.0018(Ht)+0.0016(%LW)	0.6632
Y=0.3447-0.0019(Ht)+0.0181(LW W)+0.0015(%LW)	0.6633
Y=0.3444-0.0019(Ht)+0.0000(R/in)+0.0270(LW W) +0.0015 (%LW)	0.6633

Tree Characteristics Used: Ht - Height in tree to 30 feet; R/in - Rings per inch; LW W - Latewood width; %LW - % latewood

TABLE IX

SIMPLE LINEAR REGRESSION EQUATIONS AND BEST MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING SPECIFIC GRAVITY AFTER EXTRACTION DURING THE 6 YEARS AFTER THINNING FROM EXTERNAL TREE CHARACTERISTICS OF PONDEROSA PINE

Regression Equations	Correlation Coefficient
Control Trees	
Y=0.4021-0.0039(Ht)	0.7551
Y=0.4322-0.0039(Ht)-0.0007(%L Cr)	0.7708
Y=0.4009-0.0039(Ht)-0.0008(%L Cr)+0.0011(T Ht)	0.7749
Y=0.4035-0.0040(Ht)-0.0008(%L Cr)+0.0001(BA/ac) +0.0037(DBH)	0.7782
150 Basal Area Level Trees	
Y=0.3918-0.0040(Ht)	0.7263
Y=0.6514-0.0044(Ht)-0.0053(%L Cr)	0.8785
Y=0.2488-0.0044(Ht)-0.0149(DBH)+0.0080(T Ht)	0.8892
Y=0.5731-0.0044(Ht)-0.0033(BA/ac)-0.0324(DBH) +0.0122(T Ht)	0.9189
80 Basal Area Level Trees	
Y=0.3804-0.0033(Ht)	0.7813
Y=0.4582-0.0036(Ht)-0.0014(%L Cr)	0.8370
Y=0.4080-0.0036(Ht)-0.0020(%L Cr)+0.0011(BA/ac)	0.9087
Y=).3564-0.0036(Ht)-0.0015(%L Cr)+0.0011(BA/ac) +0.0039(DBH)	0.9113
30 Basal Area Level Trees	
Y=0.3642-0.0028(Ht)	0.8460
Y=0.3035-0.0029(Ht)+0.0010(%L Cr)	0.9209
Y=0.2860-0.0031(Ht)+0.0008(%L Cr)+0.0042(DBH)	0.9438
Y=0.2798-0.0031(Ht)+0.0009(%L Cr)+0.0024(DBH) +0.0005(T Ht)	0.9442
All Trees Pooled	
Y=0.3845-0.0035(Ht)	0.7499
Y=0.3711-0.0034(Ht)+0.0001(BA/ac)	0.7884
Y=0.3156-0.0037(Ht)+0.0001(BA/ac)+0.0018(T Ht)	0.8178
Y=0.3111-0.0037(Ht)+0.0001(BA/ac)-0.0054(DBH) +0.0032(T Ht)	0.8222

External Tree Characteristics Used: Ht - Height in tree to 30 feet at which sp.gr. is being predicted; %L Cr - % live crown; BA/ac - Basal area per acre; T Ht - total tree ht.

TABLE X

SIMPLE LINEAR REGRESSION EQUATIONS AND BEST MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING SPECIFIC GRAVITY AFTER EXTRACTION DURING THE 6 YEARS AFTER THINNING FROM EXTERNAL AND INTERNAL TREE CHARACTERISTICS OF PONDEROSA PINE

Regression Equations	Correlation Coefficient
Control Trees	
Y=0.4021-0.0039(Ht)	0.7551
Y=0.3826-0.0047(Ht)+0.6591(LW W)	0.7885
Y=0.2954-0.0038(Ht)+1.435(LW W)+0.0014(R/in)	0.8668
Y=0.3409-0.0042(Ht)-0.0060(DBH)+1.646(LW W) +0.0011(R/in)	0.8720
150 Basal Area Level Trees	
Y=0.3918-0.0040(Ht)	0.7263
Y=0.6514-0.0044(Ht)-0.0053(%L Cr)	0.8785
Y=0.2488-0.0044(Ht)-0.0149(DBH)+0.0080(T Ht)	0.8892
Y=0.5731-0.0044(Ht)-0.0033(BA/ac)-0.0324(DBH) +0.0122(T Ht)	0.9189
80 Basal Area Level Trees	
Y=0.3804-0.0033(Ht)	0.7813
Y=0.4512-0.0036(Ht)-0.0076(R/in)	0.8604
Y=0.4080-0.0036(Ht)-0.0020(%L Cr)+0.0011(BA/ac)	0.9087
Y=0.3586-0.0033(Ht)-0.0017(%L Cr)+0.0011(BA/ac) +0.3079(LW W)	0.9396
30 Basal Area Level Trees	
Y=0.3642-0.0028(Ht)	0.8460
Y=0.3035-0.0029(Ht)+0.0010(%L Cr)	0.9209
Y=0.2860-0.0031(Ht)+0.0008(%L Cr)+0.0042(DBH)	0.9438
Y=0.3054-0.0031(Ht)+0.0008(%L Cr)+0.0039(DBH) -0.0018(R/in)	0.9472
All Trees Pooled	
Y=0.3845-0.0035(Ht)	0.7499
Y-0.3711-0.0034(Ht)+0.0001(BA/ac)	0.7884
Y=0.3156-0.0037(Ht)+0.0001(BA/ac)+0.0018(T Ht)	0.8178
Y=0.3111-0.0037(Ht)+0.0001(BA/ac)-0.0054(DBH) +0.0032(T Ht)	0.8222

Tree Characteristics Used: Ht - Height in tree to 30 feet; % L Cr - % live crown; BA/ac - Basal area per acre; R/in - Rings per inch; T Ht - Total tree ht.; LW W - latewood wi.

The four variables are the height at which specific gravity is being predicted, the actual basal area per acre, the diameter at breast height of the tree, and the total height of the tree. These four variables account for 67.6 per cent of the variation in specific gravity. Better correlations (up to .94) were found in individual basal area levels when, in most cases, per cent live crown was indicated to be the second best variable (Tables IX and X).

Specific Gravity Summary

In general, even though thinning tended to reduce specific gravity, there were no significant differences in either the control or the thinned trees between the pre-treatment and the after thinning periods. Specific gravity showed consistent negative relationships to crown size and a positive relationship to actual basal area per acre, with per cent live crown being the best expression of crown size.

Height in the tree and an expression of per cent latewood (either per cent latewood itself or per cent latewood volume) were found to have the most consistent relationships and high correlations with specific gravity, with specific gravity decreasing up the tree and increasing with increasing per cent latewood or per cent latewood

volume. None of the other variables (latewood width, ring width and rings per inch) were found to have a consistent relationship with specific gravity. Under the conditions of this study, multiple regression analysis showed that external characteristics were better predicters of specific gravity than internal characteristics.

III. RADIAL GROWTH

Annual earlywood and latewood increments were determined using a dendrochronograph. These values were thn converted to annual radial growth in inches and total radial increment for both the six rings before and the six rings after thinning.

Annual Radial Increment

The correlation coefficients between annual radial growth and year of formation for the pretreatment period were significant at the ten, fifteen and twenty foot height levels of the control trees and the fifteen foot height level of the 30 basal area level trees. When all the heights were combined, the control, 80 level and 30 level data showed significant correlations. All other correlation coefficients for the pretreatment period were not significant. Except in one case, all the after thinning correlations between ring width and year of formation

were significant. The one case was in the twenty foot height level of the control trees (Figures 30-34, Appendix Table XVII).

The control trees showed a decrease in the average annual radial growth of 32.5 per cent during the six year treated period over the six year pretreatment period. The decrease was significant at all height levels and when all heights were combined. In all heights of all the thinning levels there was a significant increase of annual radial growth during the treatment period over the pretreatment period. The average annual increase was 95.9 per cent in the 150 level, 114.8 per cent in the 80 level and 115.7 per cent in the 30 level (Table XI).

Analysis of variance of ring width between heights of the control trees showed that significant differences were increased with increasing distances between sample points in the bole. This was true for both the before and after treatment periods, except that these differences tended to decrease during the after treatment period (Appendix Tables LXV and LXVI). Thinning tended to decrease these differences between heights, with both the 150 and 30 basal area levels showing no differences between heights after thinning (Appendix Tables LXVII-LXXII).

Analysis of variance of annual radial increment between treatment levels shows no significant differences

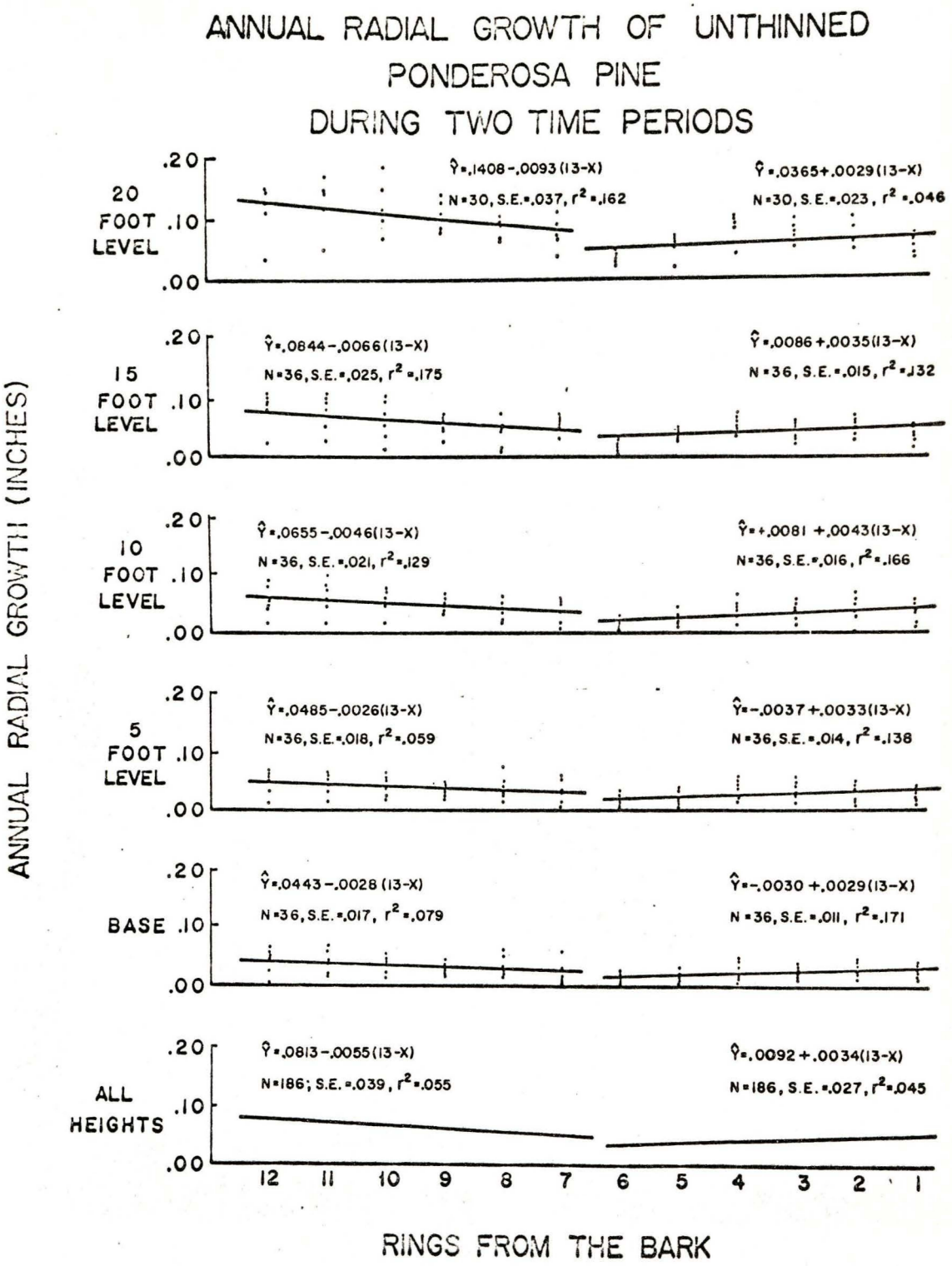
ANNUAL RADIAL GROWTH OF UNTHINNED
PONDEROSA PINE
DURING TWO TIME PERIODS
ANNUAL RADIAL GROWTH (INCHES)
20 FOOT LEVEL
Ŷ=.1408-.0093(13-X)
N=30, S.E.=.037, r²=.162
Ŷ=.0365+.0029(13-X)
N=30, S.E.=.023, r²=.046
15 FOOT LEVEL
Ŷ=.0844-.0066(13-X)
N=36, S.E.=.025, r²=.175
Ŷ=.0086+.0035(13-X)
N=36, S.E.=.015, r²=.132
10 FOOT LEVEL
Ŷ=.0655-.0046(13-X)
N=36, S.E.=.021, r²=.129
Ŷ=+.0081+.0043(13-X)
N=36, S.E.=.016, r²=.166
5 FOOT LEVEL
Ŷ=.0485-.0026(13-X)
N=36, S.E.=.018, r²=.059
Ŷ=-.0037+.0033(13-X)
N=36, S.E.=.014, r²=.138
BASE
Ŷ=.0443-.0028(13-X)
N=36, S.E.=.017, r²=.079
Ŷ=-.0030+.0029(13-X)
N=36, S.E.=.011, r²=.171
ALL HEIGHTS
Ŷ=.0813-.0055(13-X)
N=186; S.E.=.039, r²=.055
Ŷ=.0092+.0034(13-X)
N=186, S.E.=.027, r²=.045
.20
.10
.00
12 11 10 9 8 7 6 5 4 3 2 1
RINGS FROM THE BARK

Figure 30

ANNUAL RADIAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 150 BASAL AREA LEVEL

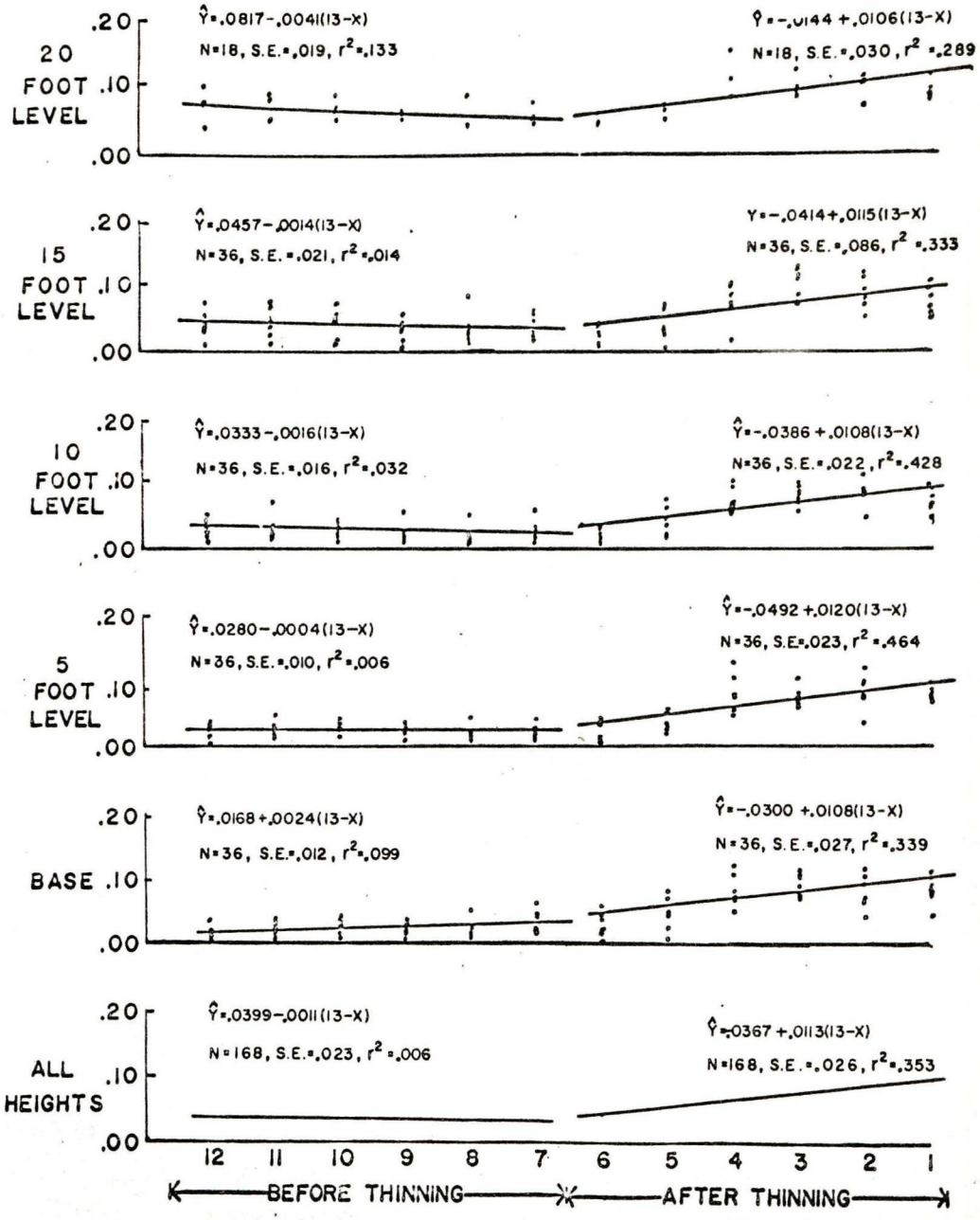

Figure 31

ANNUAL RADIAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 80 BASAL AREA LEVEL

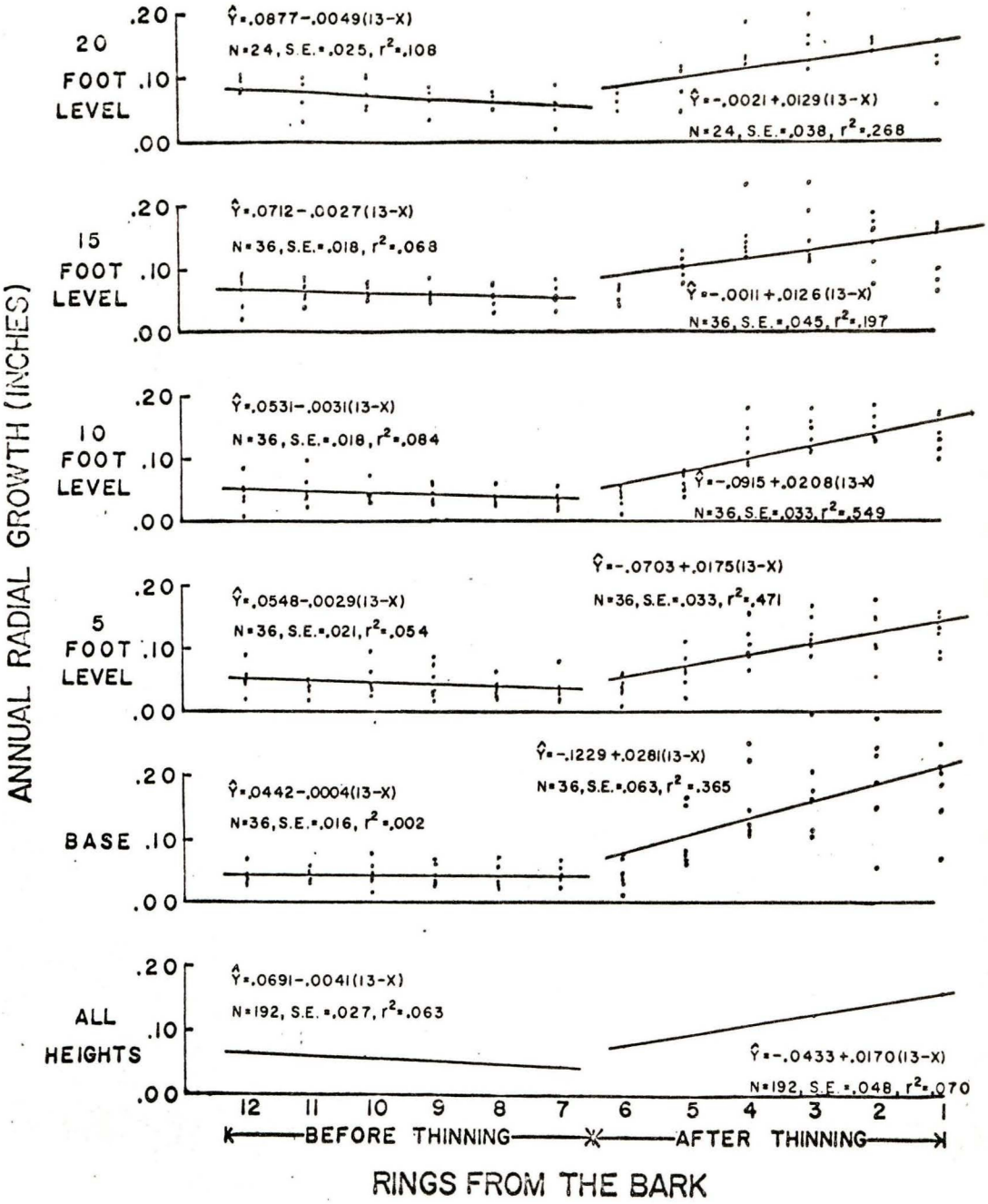

Figure 32

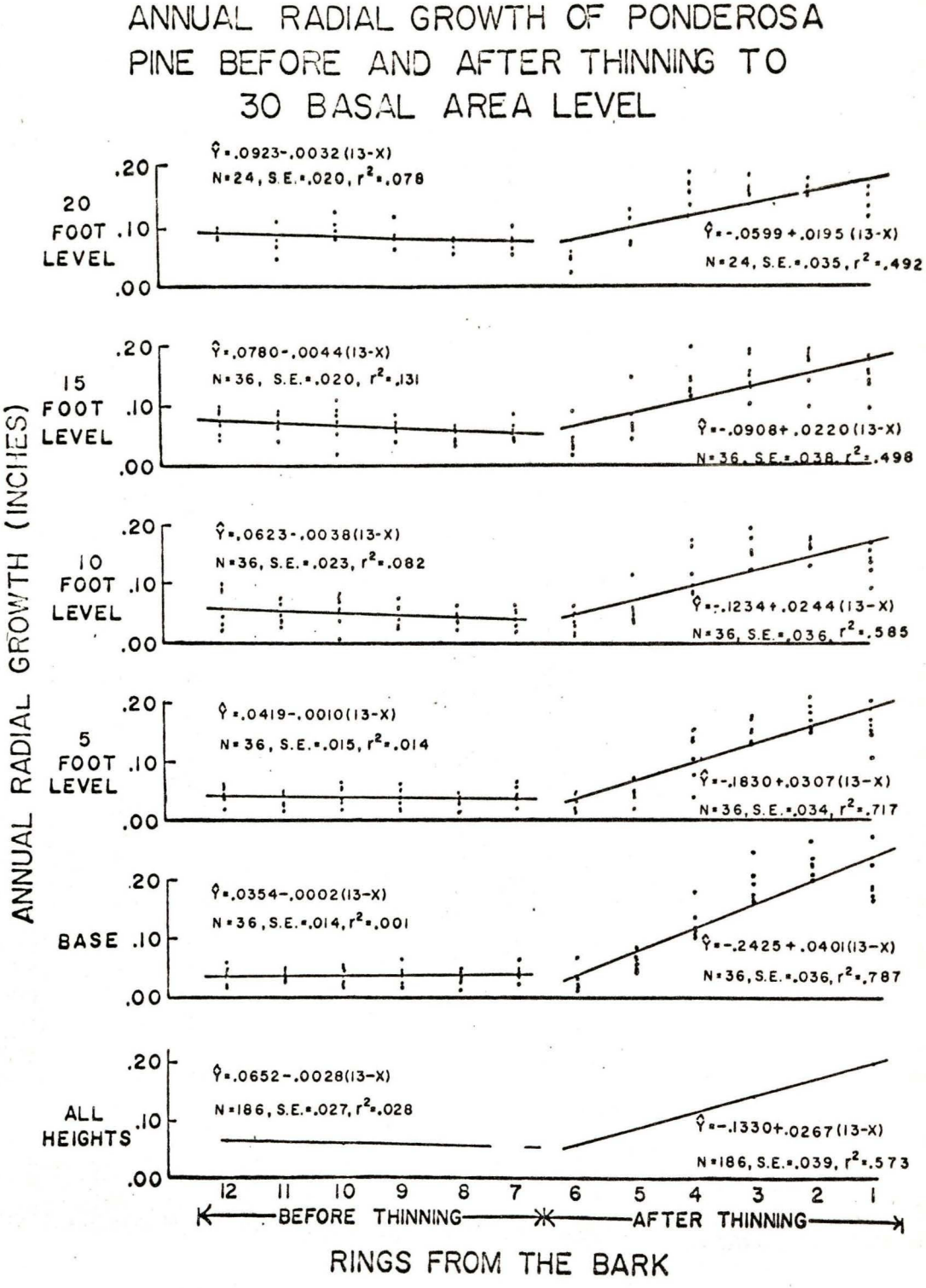
ANNUAL RADIAL GROWTH OF PONDEROSA PINE BEFORE AND AFTER THINNING TO 30 BASAL AREA LEVEL
ANNUAL RADIAL GROWTH (INCHES)
20 FOOT LEVEL
$\hat{Y}$=.0923-.0032(13-X)
N=24, S.E.=.020, r^2=.078
$\hat{Y}$=-.0599+.0195(13-X)
N=24, S.E.=.035, r^2=.492
15 FOOT LEVEL
$\hat{Y}$=.0780-.0044(13-X)
N=36, S.E.=.020, r^2=.131
$\hat{Y}$=-.0908+.0220(13-X)
N=36, S.E.=.038, r^2=.498
10 FOOT LEVEL
$\hat{Y}$=.0623-.0038(13-X)
N=36, S.E.=.023, r^2=.082
$\hat{Y}$=-.1234+.0244(13-X)
N=36, S.E.=.036, r^2=.585
5 FOOT LEVEL
$\hat{Y}$=.0419-.0010(13-X)
N=36, S.E.=.015, r^2=.014
$\hat{Y}$=-.1830+.0307(13-X)
N=36, S.E.=.034, r^2=.717
BASE
$\hat{Y}$=.0354-.0002(13-X)
N=36, S.E.=.014, r^2=.001
$\hat{Y}$=-.2425+.0401(13-X)
N=36, S.E.=.036, r^2=.787
ALL HEIGHTS
$\hat{Y}$=.0652-.0028(13-X)
N=186, S.E.=.027, r^2=.028
$\hat{Y}$=-.1330+.0267(13-X)
N=186, S.E.=.039, r^2=.573
.20
.10
.00
12 11 10 9 8 7 6 5 4 3 2 1
BEFORE THINNING
AFTER THINNING
RINGS FROM THE BARK

Figure 33

ANNUAL RADIAL GROWTH OF PONDEROSA PINE

COMPARISON OF FOUR LEVELS OF TREATMENT
BEFORE AND AFTER TREATMENT

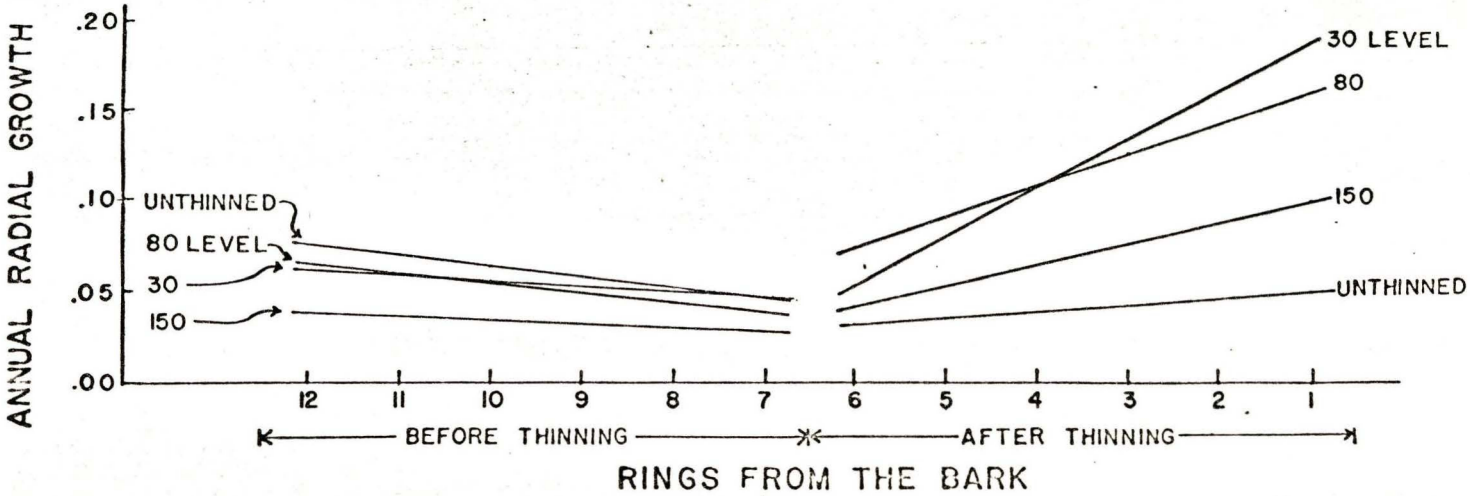

Figure 34

TABLE XI

STATISTICAL COMPARISON BETWEEN RINGS 7-12 AND 1-6 OF ANNUAL RADIAL INCREMENT BY HEIGHTS OF DIFFERENT TREATMENT LEVELS

Treatment Level	Ht.	Rings 7-12 N	Rings 7-12 Mean (In.)	Rings 1-6 N	Rings 1-6 Mean (In.)	% Incr. or Decr.	DF	$S.E._d$	"t" (one-tailed)
Unthinned	Base	36	.035	36	.025	-27.7	64	.0035	2.735**
	5'	36	.039	36	.028	-29.4	70	.0040	2.878**
	10'	36	.049	36	.032	-34.1	70	.0048	3.519**
	15'	36	.061	36	.042	-31.9	57	.0054	3.637**
	20'	30	.108	30	.064	-40.4	47	.0085	5.133**
	All	186	.062	186	.042	-32.5	327	.0036	5.616**
150 Basal Area Level	Base	36	.025	36	.073	192.8	46	.0058	8.336**
	5'	36	.026	36	.065	146.3	43	.0054	7.193**
	10'	36	.028	36	.064	133.2	55	.0055	6.710**
	15'	36	.041	36	.068	67.4	58	.0068	4.057**
	20'	18	.067	18	.086	28.0	27	.0094	1.998*
	All	168	.036	168	.071	95.9	302	.0031	11.198**
80 Basal Area Level	Base	36	.043	36	.144	235.6	38	.0317	7.386**
	5'	36	.045	36	.096	115.8	51	.0082	6.288**
	10'	36	.042	36	.106	150.8	45	.0087	7.349**
	15'	36	.062	36	.120	94.9	44	.0087	6.732**
	20'	24	.070	24	.120	70.8	38	.0103	4.827**
	All	192	.055	192	.118	114.8	280	.0045	13.984**
30 Basal Area Level	Base	36	.036	36	.138	280.3	37	.0132	7.693**
	5'	36	.038	36	.108	182.0	39	.0107	6.526**
	10'	36	.049	36	.109	122.3	47	.0100	5.979**
	15'	36	.063	36	.118	88.4	46	.0100	5.728**
	20'	24	.081	24	.126	55.5	31	.0108	4.168**
	All	186	.056	186	.120	115.7	258	.0048	13.317**

NS - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

between the control trees and the 30 level trees during the pretreatment period and between the 30 and 80 level trees during both the pretreatment and treated periods. All other comparisons were significantly different (Appendix Tables LXXIII and LXXIV).

Thinning increased annual radial growth, with progressively less response with increasing height in the tree and increasing basal area.

Width of the Six Rings Segments

Width of the six ring segment after thinning increased with increasing per cent live crown. The correlation coefficients between width of the six ring segment after thinning and per cent live crown were significant at each height of the sample trees and when all heights were combined. The highest correlation coefficient was at the ten foot level or approximately the average crown base. At this height 35 per cent of the variation in the width of the six ring segment was accounted for by the per cent of live crown (Figure 35, Appendix Table XVIII). Over 26 per cent of the variation in per cent live crown was shown to be associated with actual basal area per acre.(Figure 36, Appendix Table XVIII).

When width of the six ring segment, after thinning, was expressed as rings per inch, the correlation with

WIDTH OF SIX RING SEGMENT — PERCENT LIVE CROWN RELATIONSHIP DURING THE SIX YEARS AFTER THINNING PONDEROSA PINE TO FOUR BASAL AREA LEVELS

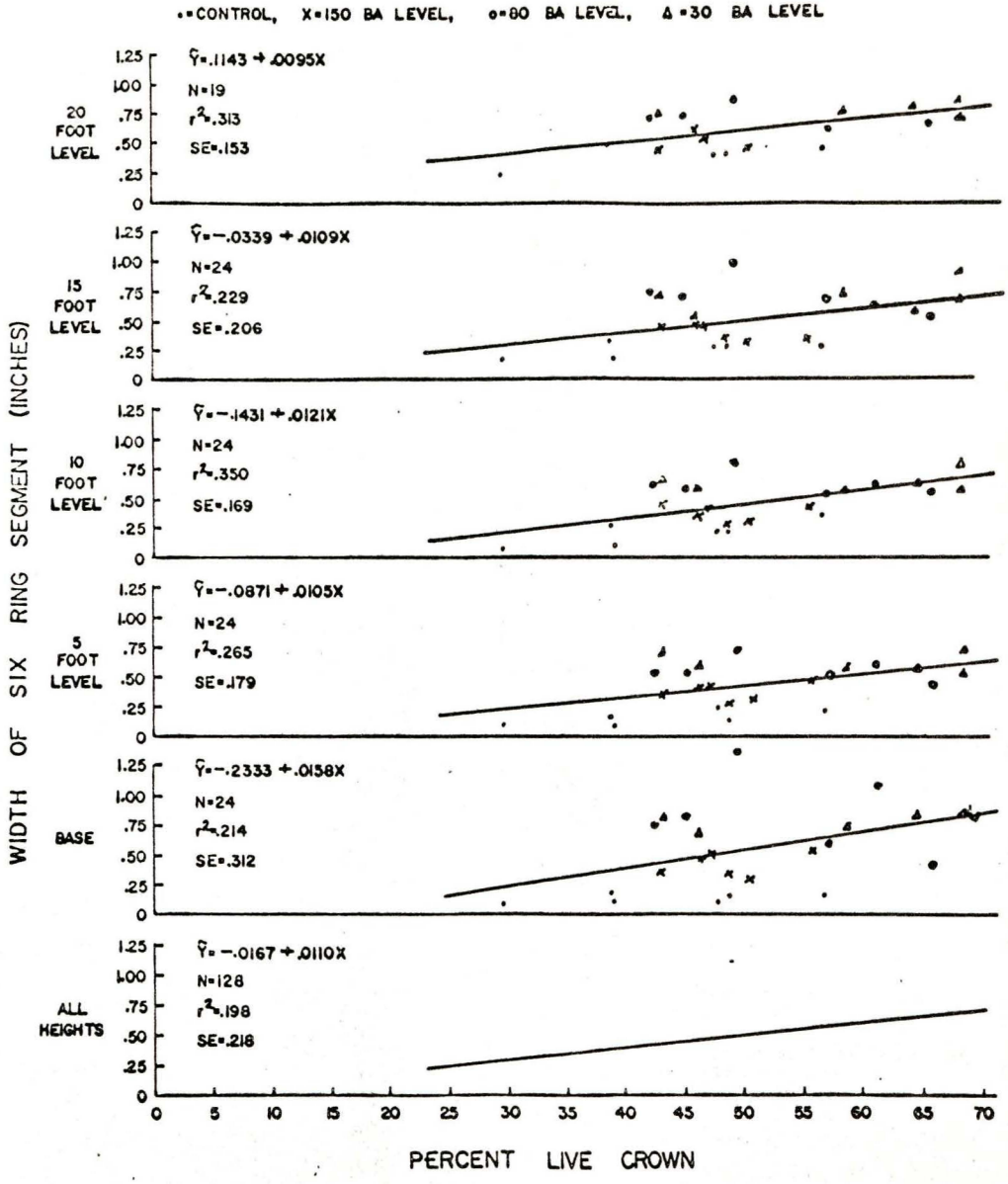

Figure 35

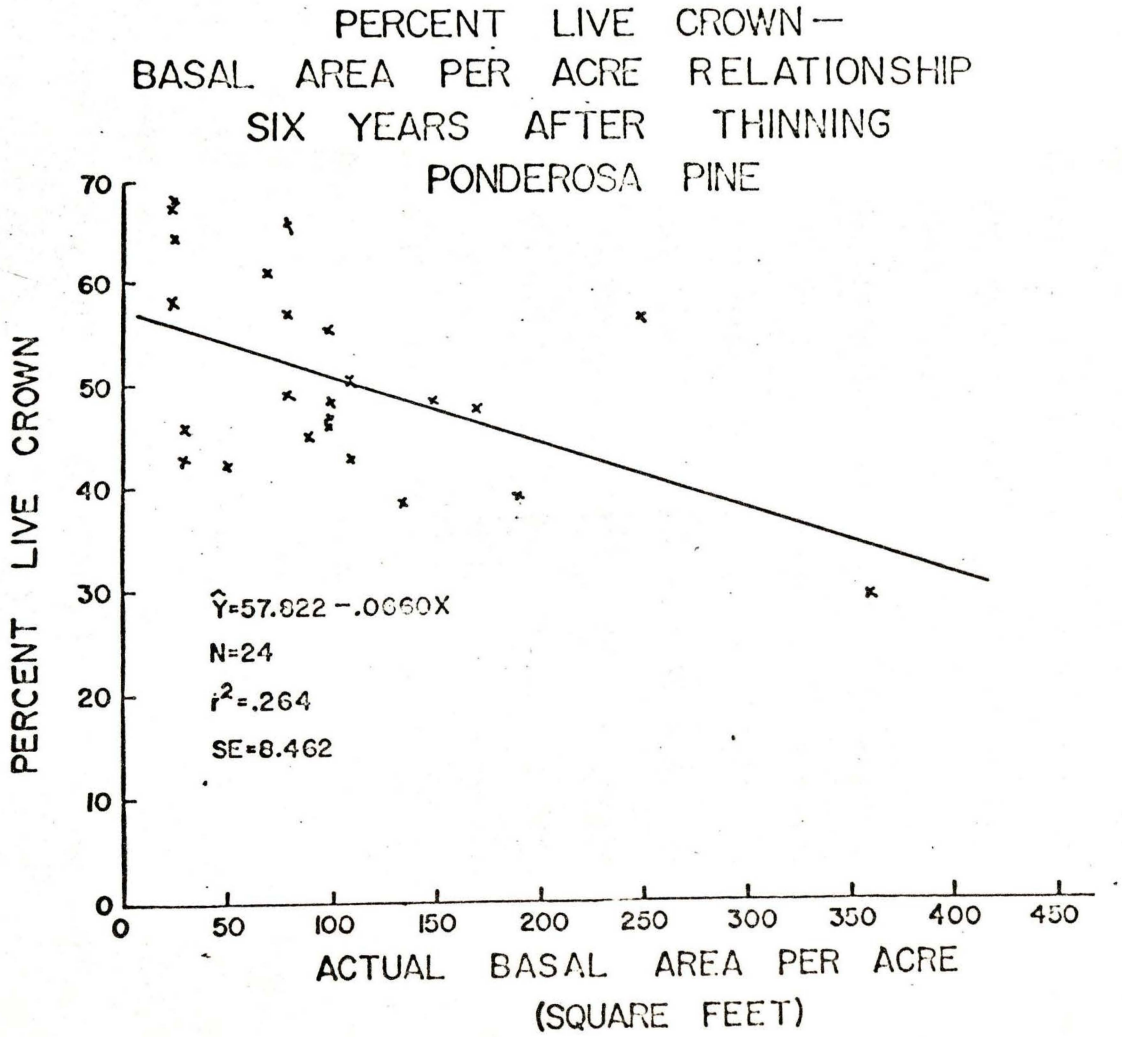
PERCENT LIVE CROWN —
BASAL AREA PER ACRE RELATIONSHIP
SIX YEARS AFTER THINNING
PONDEROSA PINE
PERCENT LIVE CROWN
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
ACTUAL BASAL AREA PER ACRE
(SQUARE FEET)
Ŷ=57.822 −.0660X
N=24
r²=.264
SE=8.462

Figure 36

actual basal area per acre was significant at all height levels. When all heights were combined basal area per acre accounted for 57 per cent of the variation in rings per inch with individual heights having higher correlations between rings per inch and basal area per acre. Rings per inch showed a direct relationship to basal area per acre (Figure 37, Appendix Table XVIII).

Figure 38 was drawn to show the "average" tree of each treatment level. The "average" tree was determined by calculating the mean radii of the core (from the pith to ring number 13 from the bark) and the mean radii from the pith through ring number seven and ring number one at five foot height intervals of the six sample trees for each basal area level. The average taper per feet, as calculated from the diameter inside the bark, from the base to 20 feet is shown in Appendix Table XIX.

Appendix Table XIX shows that the unthinned trees continued to decrease in taper from the core to ring number seven and then from ring number seven to ring number one. The table also shows that thinning reversed this trend and increased taper.

Annual Increment as Related to Selected External and Environmental Factors

No scientific estimation of the date or factors influencing the initiation of latewood in ponderosa pine

RINGS PER INCH — BASAL AREA PER ACRE
RELATIONSHIP IN THINNED PONDEROSA PINE

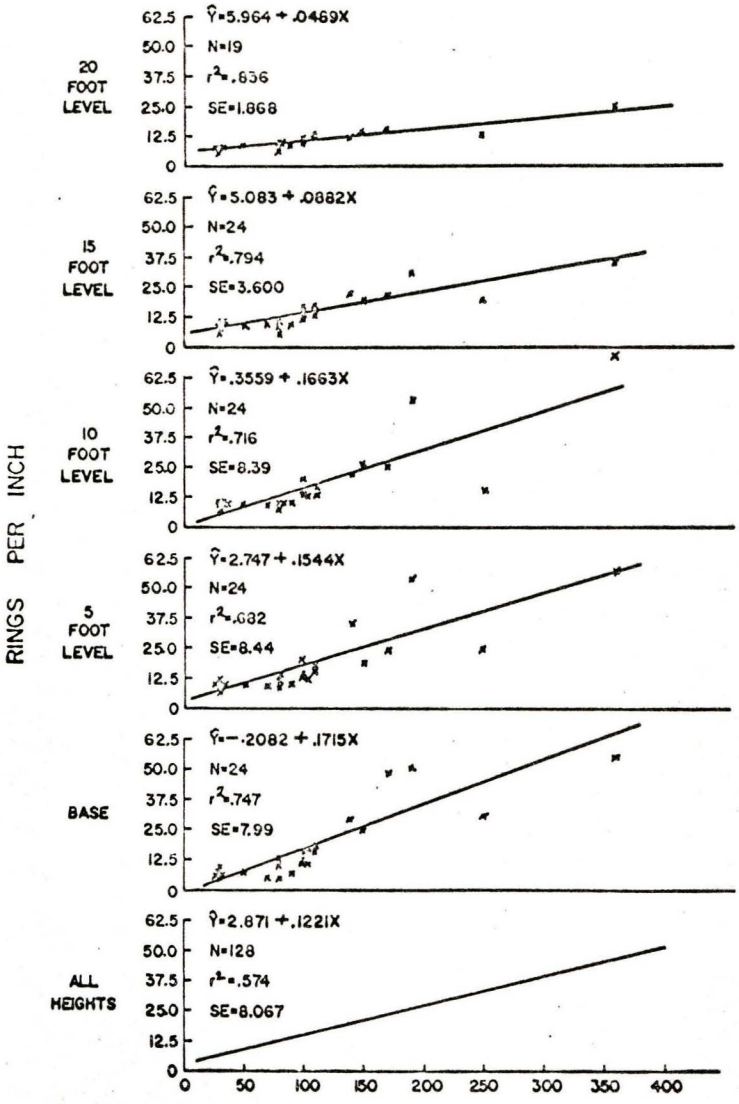

Figure 37

INFLUENCE OF HEIGHT ON TREE FORM, BEFORE AND AFTER THINNING PONDEROSA PINE

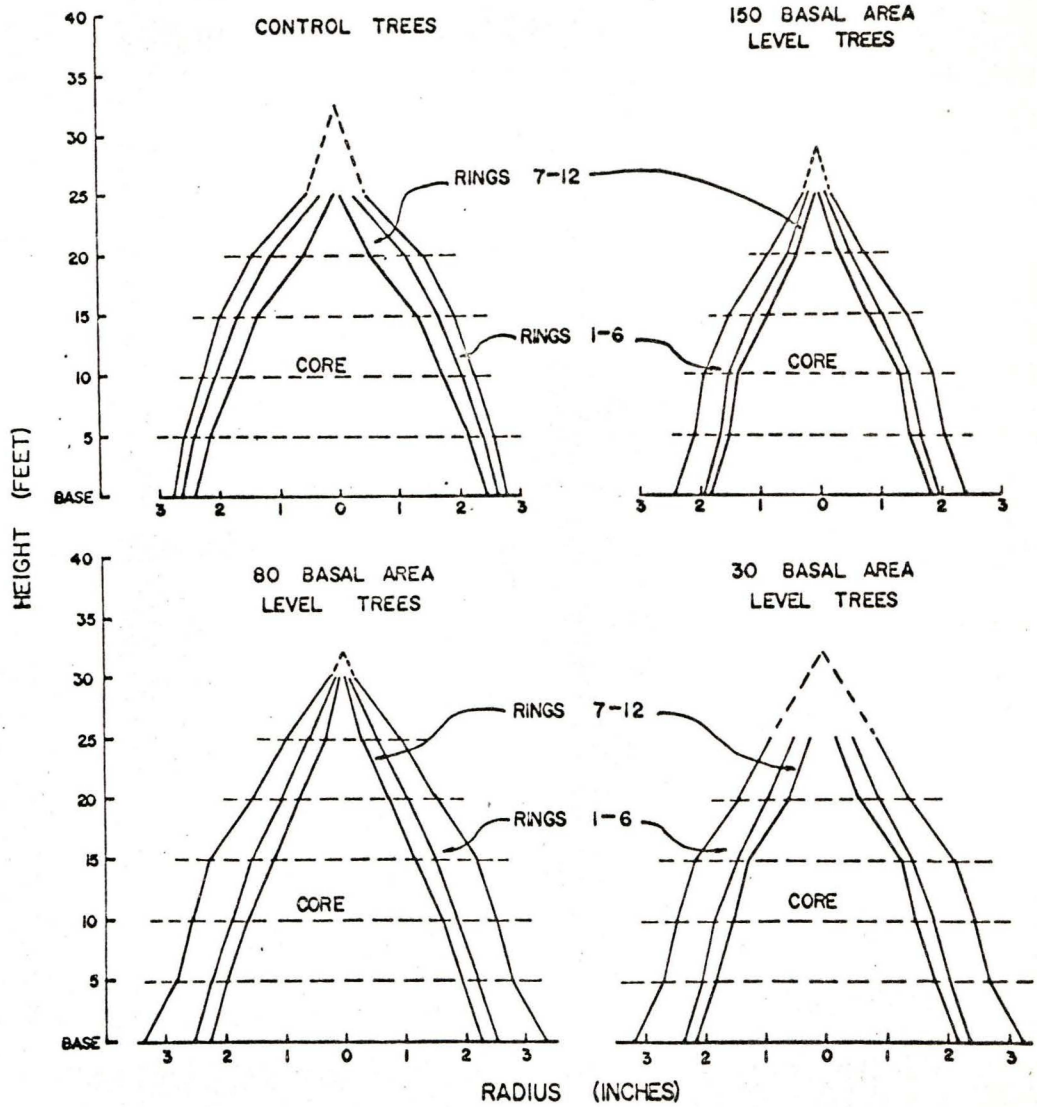

Figure 38

could be found in the literature, so a limited study was undertaken during the growing season of 1969. This limited sample was intended to generate a hypothesis as to the approximate date of latewood initiation in ponderosa pine. The sample indicated that latewood production in ponderosa pine is initiated very late in the growing season which would account for the narrow bands of latewood encountered in most ponderosa pine trees. A study currently underway is intended to test this hypothesis.

Table XII shows the best four variables, when used in a multiple regression, that will predict ring, early-wood and latewood width. The six rings after thinning of all heights of all trees sample were pooled. The best four variables that will predict annual earlywood growth are the number of years after thinning, basal area per acre, and the rainfall in May and June. These variables accounted for 52 per cent of the variation in earlywood width. Crown size showed continuously as the best variable to predict latewood width. Crown volume accounted for over 25 per cent of the variation in annual latewood width. When the number of years since thinning, basal area per acre and rainfall in August were added to crown size, together they accounted for 36.5 per cent of the variation in annual latewood width. Crown surface area, basal area per acre, rainfall in June and the mean minimum temperature

TABLE XII

SIMPLE LINEAR REGRESSION EQUATIONS AND BEST MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING ANNUAL INCREMENT AFTER THINNING FROM EXTERNAL TREE CHARACTERISTICS AND ENVIRONMENTAL FACTORS

Regression Equations	Correlation Coefficient
Ring Width	
$Y=0.1268-0.004(BA/Ac)$	0.5001
$Y=0.0126+0.0147(13\text{-}Ring\#)-0.0004(BA)$	0.6645
$Y=0.6372-0.0004(BA)+0.0318(Rain\ in\ June)-0.0197(Mean\ min.temp.in\ May)$	0.7066
$Y=0.5908+0.0001(Crown\ surface)-0.0003(BA)+0.0318(Rain\ in\ June)-0.0197(Mean\ min.temp.in\ May)$	0.7360
Earlywood Width	
$Y=0.1092-0.0003(BA)$	0.4815
$Y=0.0181+0.0134(13\text{-}Ring\#)-0.0003(BA)$	0.6545
$Y=0.5717-0.0003(BA)+0.0293(Rain\ in\ June)-0.0179(Mean\ min.temp.in\ May)$	0.6995
$Y=0.0006+0.0086(13\text{-}Ring\#)-0.0003(BA)+0.0155(Rain\ in\ May)+0.0230(Rain\ in\ June)$	0.7221
Latewood Width	
$Y=0.0062+0.0015(Crown\ volume)$	0.5061
$Y=0.0116+0.0015(Crown\ volume)-0.0015(Rain\ in\ Aug)$	0.5630
$Y=-0.0043+0.0028(Crown\ surface)+0.0013(13\text{-}Ring\#)-0.0027(BA)$	0.5873
$Y=0.0032+0.0028(Crown\ surface)+0.0009(13\text{-}Ring\#)-0.0027(BA)-0.0010(Rain\ in\ Aug)$	0.6039

Variables Used in Regression Analysis:

X_1 = Crown surface area
X_2 = Per cent live crown
X_3 = Crown volume
X_4 = Height in tree
X_5 = 13-Ring # from bark
X_6 = Basal area per acre
X_7 = Rain in May
X_8 = Rain in June
X_9 = Rain in July
X_{10} = Rain in August
X_{11} = Rain in September
X_{12} = Mean min. temp. in May
X_{13} = Mean min. temp. in June
X_{14} = Mean min. temp. in Aug.
X_{15} = Mean min. temp. in Sept.

in May accounted for 54.2 per cent of the variation in annual radial increment.

The correlations obtained from the multiple regressions reported above indicate that all the variables were not measured that affect annual increment, or those variables that were not measured were not sufficiently sensitive. Possibly the monthly means should have been weekly means and other environmental factors might have been included to obtain higher correlations.

Radial Growth Summary

Thinning increased annual radial growth, with progressively less response up the bole, thus increasing tree taper. Per cent increase in annual growth decreased with increasing basal area per acre. Per cent live crown also decreased with increased stand density as did the rate of growth. Multiple regression analysis showed that basal area per acre, crown size and rainfall were the best indicators of annual growth.

CHAPTER V

DISCUSSION AND SUMMARY

During September and October 1962, thinning plots were established at the Taylor Woods unit of the Fort Valley Experimental Forest. Eighteen plots were thinned to six different basal area levels ranging from 30 to 150 square feet and three were left as unthinned control plots. Six trees from each of the 30, 80 and 150 basal area levels plus six trees from the unthinned plots were sampled in 1969 at five foot intervals up the bole. The six years after thinning were then compared with the six years before thinning to determine the effect of thinning on growth and specific gravity.

The first objective of the study was to "determine the response to thinning at different basal area levels in terms of radial growth rate, volume growth, specific gravity, and per cent latewood."

1. Radial growth rate was increased by thinning, with a positive relationship to basal area per acre. The unthinned trees showed a decrease in rate of growth. A few of the authors that have reported the same findings are: Lowery and Schmidt (1967), Zahner (1958) Paul (1957, 1963), Paul and Smith (1956), Smith (1968)

and, in ponderosa pine, Krauch (1924), Schubert and Martin (1969), and Paul and Meagher (1949).

2. Volume growth per tree increased due to thinning while the unthinned trees showed a decrease in the average annual volume growth. Of the thinning levels studied, the volume growth per acre was approximately the same between the 80 and the 150 basal area levels while the 30 basal area level was lower in volume growth per acre. This indicates that the 30 level was not fully utilizing the site. Most of the authors listed above also indicated an increase in volume growth per tree due to thinning.

3. Specific gravity did not change significantly in either the thinned or unthinned trees, during the after thinning period when compared to the before thinning period. Most of the studies reported in the literature indicate, that in conifers, thinning reduced specific gravity (Paul and Smith 1956, Paul and Meagher 1949, and Paul 1963). However, it has also been reported that thinning increased specific gravity (Paul 1957, Lowery and Schmidt 1957, and Smith 1969) and that thinning caused fluctuations to occur in specific gravity (Paul 1963).

4. Per cent latewood increased from the before thinning period to the after thinning period in the unthinned trees. In general, however, thinning tended to decrease per cent latewood, although in most cases this decrease was not significant.

The second objective of this study was to "compare the quality of the wood after thinning with that before thinning and with unthinned trees." The expression of wood quality used in this study was specific gravity based on extractive free wood. As has been reported earlier, specific gravity for the six years after thinning was not affected significantly by thinning when compared to the prethinned period. Any differences between levels of thinning were masked by inherent differences between levels that were present before thinning. This was true for specific gravity and all other variables.

The third and last objective of this study was to "establish relationships between selected environmental and morphological characteristics, and specific gravity and latewood width."

1. Specific gravity decreased with
   a. increasing crown size
   b. increasing height in the tree
   c. decreasing basal area per acre
   d. decreasing per cent latewood

None of the other variables (latewood width, ring width, and rings per inch) measured were found to have a consistent relationship to specific gravity.

The negative relationship of specific gravity to tree height, in conifers, has been reported previously by Conway and Minor (1961), Cockrell (1943), Wahlgren, Hart, and Maeglin (1966), and Paul (1957). The relationship of specific gravity increasing with increasing per cent latewood has also been reported by many authors (McKimmy 1959, Paul and Smith 1956, Zahner 1958, Drow 1957, and Zobel and Rhodes 1955). The literature is in a state of confusion on the relationship between specific gravity and basal area per acre. Some authors reported a positive relationship and others a negative one and still others reported no relationship at all. These last articles indicated rate of growth as the more sensitive variable which can be subsequently related to basal area per acre. Some articles reported that the relationship depended upon tree size.

Under the conditions of this study, multiple regression analysis showed that external tree characteristics (height in the tree, basal area per acre, diameter breat high, total tree height, and per cent live crown) were better predictors of specific gravity than internal characteristics.

2. Latewood width was not shown to have a high correlation to any single or multiple environmental factors measured. Crown size was the single best variable and accounted for approximately 25 per cent of the variation in latewood width.

Since differences between levels existed before thinning the differences after thinning cannot be adequately analyzed. However, if per cent response is employed, it can be shown that thinning increased radial and volume growth per tree. Large differences were shown in per cent response, between the control trees and basal area level trees and also between the 150 basal area level trees and the 30 and 80 basal area level trees. However, there were only slight differences between the 80 and 30 level trees.

It can then be said that the results of this study indicate that, for the conditions reported, thinning increases rate of diameter growth and volume growth per tree, does not affect specific gravity and increases tree taper in young-growth ponderosa pine.

CHAPTER VI

RECOMMENDATION FOR FURTHER RESEARCH

From the results of this study the immediate effects of thinning on rate of diameter growth, volume growth and specific gravity can be predicted at several different thinning levels for one soil type and site index of the southwestern ponderosa pine ~~tree~~ type.

1. It is recommended that this study, at Taylor Woods, continue so that the information needed on the long range effects of thinning can be provided.
2. Several limited studies, of the Taylor Woods type, should be started on several different soil types and site indexes. This should be done, in order to provide information on the effects of thinning on tree growth and quality on a range of site indexes.
3. Some study should be given to the possible different responses of different ages and size classes, of ponderosa pine, to thinning.

BIBLIOGRAPHY

BIBLIOGRAPHY

Bannan, M. W. 1962. In "Tree Growth" (T. T. Kozlowski, ed.). Ronald Press Co. N.Y. pp. 3-32.

Byram, G. M. and W. T. Doolittle. 1950. A Year of Growth for a Shortleaf Pine. Ecology 31:27-35.

Chalk, L. 1930. The Formation of Spring and Summerwood in Ash and Douglas-fir. Oxford Forestry Memoirs #10. 48pp.

Cockrell, R. A. 1943. Some Observations on Density and Shrinkage of Ponderosa Pine Wood. The American Society of Mechanical Engineers. 10 pp.

Conway, E. M. and Co. O. Minor. 1961. Specific Gravity of Arizona Ponderosa Pine Pulpwood. Rocky Mt. Forest and Range Exp. Sta. Research Note No. 54.

Cooper, G. A. 1960. Specific Gravity of Red Pine as Related to Stem and Crown-Formed Wood. Iowa State Jour. of Science. Vol: 34 No. 4, May 15, 1960. pp. 693-708.

Diniwoodie, J. M. and S. D. Richardson. 1960. Studies in the Physiology of Xylem Development. Journal of the Institute of Wood Science. Vol:6. pp. 3-13.

Drow, J. T. 1957. Relationship of Locality and Rate of Growth to Density and Strength of Douglas-fir. USFS FPL #2078. 56 pp.

Echols, R. M. 1958. Variation in Tracheid Length and Wood Density in Geographic Races of Scotch Pine. Yale Univ. Bulletin No. 64. 52 pp.

Englerth, G. H. 1966. Framework of Qualitative Relationships in Wood Utilization. USFS FPL Research Paper #45. 16 pp.

Fielding, J. M. and A. G. Brown. 1960. Variations in the Density of the Wood of Monterey Pine From Tree to Tree. Australian Forestry and Timber Bureau Leaflet #77. 28 pp.

Forest Products Laboratory. 1965. Western Wood Density Survey. USFS Research Paper FPL-27. 58 pp.

Forrer, W. C. 1968. Englemann Spruce Flexes Its Muscle. Colorado State Univ. and USFS #2.

Fowells, H. A. 1941. The Period of Seasonal Growth of Ponderosa Pine and Associated Species. J. For. 39:601-608.

Freese, F. 1967. Elementary Statistical Methods for Foresters. USDA Agricultural Handbook 317. 87 pp.

Gaertner, E. E. 1961. In "The Water Relations of Plants" (Rutter and Whitehead, ed.). John Wiley and Sons Inc. N.W. pp. 366-375.

Glock, W. S. 1955. Growth Rings and Climate. Botanical Review. 21:73-188.

_____, and S. R. Agerter. 1962. In "Tree Growth" (T. T. Kozlowski. ed.). Ronald Press Co. N.Y. pp. 23-56.

Hale, J. D. and J. B. Prince. 1940. Density and Rate of Growth in the Spruces and Balsam Fir of Eastern Canada. Dominion Forest Service. Bulletin #94.

_____, and K. G. Fensom. 1931. The Rate of Growth and Density of the Wood of the White Spruce. Canadian F.S. Circular No. 30. 19 pp.

Hall, A. D. 1963. The Fibre Characteristics of Black Spruce in Relation to Wood Quality. Canadian Dept. of Lands and Forests Research Report #49. 23 pp.

Harlow, W. M. and E. S. Harrar. 1958. Textbook of Dendrology. McGraw-Hill Book Co., Inc. 561 pp.

Hellmers, H. 1962. In "Tree Growth" (T. T. Kozlowsky, ed.). Ronald Press Co., N. Y. pp. 275-280.

Keith, C. T. 1961. Characteristics of Annual Rings in Relation to Wood Quality in White Spruce. Forest Products Jour. 11:(no. 3) 122-126.

Kramer, P. H. 1964. In "The Formation of Wood in Forest Trees" (Zimmermann, ed.). Academic Press. N.Y. pp. 519-532.

Krauch, H. 1924. Acceleration of Growth in Western Yellow Pine Stands After Cutting. J. For. 22:(No. 6)39-42.

Larson, P. R. 1962. In "Tree Growth" (T. T. Kozlowski, ed.). Ronald Press Co., N.Y. pp. 97-118.

_____. 1964. In "The Formation of Wood in Forest Trees" (Zimmermann, ed.). Academic Press. N.Y. pp. 345-366.

Lowery, D. P. and W. C. Schmidt. 1967. Effect of Thinning on the Specific Gravity of Western Larch Crop Trees. USFS Research Note INT-70. 6 pp.

Marts, R. O. 1949. Effect of Crown Reduction on Taper and Density in Longleaf Pine. Southern Lumberman, Dec. 15. pp. 1-4.

_____. 1950. Wood Quality of Bud Pruned Longleaf Pine. Southern Lumberman. Dec. 15. pp. 1-3.

McGinnes, E. A. Jr. 1963. Growth-Quality Evaluation of Missouri-Grown Shortleaf Pine. Univ. of Missouri Res. Bull. #841. 59 pp.

McKimmy, M. D. 1959. Young Growth Douglas-fir. State of Oregon Forest Products Research Center. Bulletin #8. 52 pp.

Northcott, P. L. 1965. The Comparison of Tree Qualities. For. Chronical June Vol:41, No. 2.

Paul, B. H. 1957. Growth and Specific Gravity Responses in a Thinned Red Pine Plantation. J. For. 55:510-512.

_____. 1963. The Application of Silviculture in Controlling the Specific Gravity of Wood. USFS Tech. Bul. #1288. 97 pp.

_____, and R. O. Marts. 1954. Controlling the Proportion of Summerwood in Longleaf Pine. USFS Report No. 1988. 6 pp.

_____, and G. Meagher. 1949. Growth-Quality Study of Ponderosa Pine. USFS FPL. 14 pp.

Paul, B. H. and D. M. Smith. 1956. Summary on Growth in Relation to Quality of Southern Yellow Pine. USFS USPL No. 1751. 22 pp.

Pearson, G. A. 1942. The Growing Season of Western Yellow Pine. J. Agr. Research 29:203-204.

_____. 1950. Management of Ponderosa Pine in the Southwest. Agr. Monogrpah No. 6. 218 pp.

Richardson, S. D. 1964. In "The Formation of Wood in Forest Trees" (Zimmermann, ed.). Academic Press, N.Y. pp. 367-388.

Schafer, E. R. 1949. The Influence of Volume of Summerwood and Rate of Growth on the Specific Gravity of Southern Pine Pulpwood. Southern Pulp and Paper Manufacturers. Oct. 31. 3 pp.

Schubert, G. H. and E. C. Martin. 1969. Five Year Growth of Ponderosa Pine Related to Growing Stock Levels on Taylor Woods Plot in Arizona. USFS Unpublished Preliminary Report. 51 pp.

Smith, D. M. 1968. Wood Quality of Loblolly Pine After Thinning. USFS FPL #89. 12 pp.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods. The Iowa State Univ. Pres. Ames, Iowa. 593 pp.

U. S. Dept. of Commerce, Environmental Sciences Services Administration. Local Climatological Data for Flagstaff, Arizona.

Voorhies, G. 1969a. Wood Quality of Young-Growth Ponderosa Pine After Thinning. Study Plan FS-RM-1203.35. NAU and RMF and RES. 11 pp.

_____. 1969b. Specific Gravity Studies of Young Growth Southwestern Ponderosa Pine. Forest Products Jour. 19:45-46.

Wahlgren, H. E., G. Baker, R. R. Maeglin and A. C. Hart. 1968. Survey of Specific Gravity of Eight Maine Conifers. USFS Res. Paper FPL #95. 12 pp.

Wahlgren, H. E., A. C. Hart and R. R. Maeglin. 1966. Estimating Tree Specific Gravity of Maine Conifers. USFS Research Paper FPL #61. 22 pp.

Wilde, S. A. and B. H. Paul. 1959. Growth, Specific Gravity, and Chemical Compositions of Quaking Aspen on Different Soil Types. FPL #2144.

Wort, D. J. 1962. In "Tree Growth" (T. T. Kozlowski, ed.). Ronald Press Co., N.Y. pp. 89-96.

Yandle, D. O. 1956. Statistical Evaluation of the Effect of Age on Specific Gravity in Loblolly Pine. USFS FPL #2049. 15 pp.

Zahner, R. 1958. Hardwood Understory Depletes Water in Pine Stands. Forest Sci. 4(3):178-184.

Zobel, B. J. and R. R. Rhodes. 1955. Relationship of Wood Specific Gravity in Loblolly Pine to Growth and Environmental Factors. Texas Forest Service Tech. Report #11. 32 pp.

APPENDIX

TABLE XIII

SIMPLE CORRELATIONS BETWEEN VOLUME FEATURES AND RING NUMBER FOR DIFFERENT HEIGHTS AND TREATMENT LEVELS. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATIONS COEFFICIENT, r). (RINGS WERE NUMBERED RROM THE BARK AND RING 7-12 AND RINGS 1-6 REPRESENT BEFORE AND AFTER THINNING RESPECTIVELY).

	Bolt No.	Rings 7-12				Rings 1-6			
		Control	150B.A. Level	80B.A. Level	30B.A. Level	Control	150B.A. Level	80B.A. Level	30B.A. Level
% of 12 year Volume	1	N.S.	N.S.	N.S.	N.S.	.539**	.836**	.829**	.932**
	2	N.S.	N.S.	N.S.	N.S.	.580**	.811**	.822**	.884**
	3	.356*	N.S.	N.S.	N.S.	.539**	.772**	.814**	.878**
	4	N.S.	N.S.	N.S.	N.S.	.374*	.794**	.726**	.904**
	All	.231**	N.S.	N.S.	N.S.	.519**	.640**	.763**	.884**
Annual Volume	1	N.S.	N.S.	N.S.	N.S.	.417*	.644**	.637**	.857**
	2	N.S.	N.S.	N.S.	N.S.	.382*	.653**	.723**	.811**
	3	N.S.	N.S.	N.S.	N.S.	.386*	.586**	.619**	.753**
	4	N.S.	N.S.	N.S.	N.S.	.353*	.666**	.666**	.824**
	All	N.S.	N.S.	N.S.	N.S.	.371**	.621**	.590**	.769**
Accumulated Volume	1	N.S.	N.S.	N.S.	N.S.	N.S.	.368*	.457**	.433**
	2	N.S.	N.S.	N.S.	N.S.	N.S.	.333*	.449**	.399**
	3	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	.454**	.375*
	4	.415*	N.S.	.669**	N.S.	N.S.	.519*	.856**	.501*
	All	N.S.	N.S.	N.S.	N.S.	N.S.	.307**	.397**	.376**

N.S. - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XIV

SIMPLE CORRELATIONS BETWEEN ANNUAL VOLUME AND PER CENT LATEWOOD VOLUME FOR DIFFERENT HEIGHTS AND THINNING LEVELS. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATION COEFFICIENT). (RINGS WERE NUMBERED FROM THE BARK AND RINGS 7-12 AND RINGS 1-6 REPRESENT BEFORE AND AFTER THINNING RESPECTIVELY.)

	Bolt No.	ANNUAL VOLUME							
		Rings 7-12				Rings 1-6			
		Control	150 BA Level	80 BA Level	30 BA Level	Control	150 BA Level	80 BA Level	30 BA Level
% Latewood Volume	1	.507**	.601**	.495**	N.S.	.503**	.547**	.486**	.563**
	2	.617**	.718**	.578**	N.S.	.476**	.624**	.527**	.482**
	3	.404*	.640**	.414*	.477**	.381*	.428**	.399*	N.S.
	4	.357*	.501*	.655**	.611**	N.S.	.523*	.438*	N.S.
	All	.488**	.623**	.400**	.224**	.494**	.520*	.386**	.395**

N.S. - Not Significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XV

SIMPLE CORRELATIONS BETWEEN SPECIFIC GRAVITY AFTER THINNING AND BASAL AREA AND CROWN MEASUREMENTS AFTER THINNING FOR DIFFERENT HEIGHTS. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATION COEFFICIENT, r).

	HT.	Basal Area Per Acre (Sq.Ft.)	Per Cent Live Crown	Crown Surface Area (Sq.Ft.)	Crown Volume (Cr.Ft.)
Specific Gravity After Extraction	Base	.5021*	N.S.	N.S.	N.S.
	5 Feet	.5425**	.4597*	N.S.	N.S.
	10 Feet	N.S.	.4668*	N.S.	N.S.
	15 Feet	N.S.	N.S.	N.S.	N.S.
	20 Feet	N.S.	N.S.	N.S.	N.S.
	All Hts.	.2886**	.2075*	.1917*	.1962*

N.S. - Not Significant

* - Significant at the 5% level

** - Significant at the 1% level

TABLE XVI

SIMPLE CORRELATIONS BETWEEN SPECIFIC GRAVITY AND TREE FEATURES FOR DIFFERENT TREATMENT LEVELS. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATION COEFFICIENT, r). (RINGS WERE NUMBERED FROM THE BARK AND RINGS 7-12 AND 1-6 REPRESENT BEFORE AND AFTER THINNING RESPECTIVELY).

		Treatment Level	Per Cent Latewood Volume	Per Cent Latewood	Width of Six Ring Segment	Latewood Width	Rings Per Inch	Height
Specific Gravity After Extraction	Rings 7-12	Control	.710**	.697**	.363*	N.S.	.534**	.611**
		150 B.A. Level	.441*	.450*	N.S.	N.S.	N.S.	.598**
		80 B.A. Level	.609**	.696**	.476**	N.S.	.421**	.586**
		30 B.A. Level	N.S.	N.S.	.475**	N.S.	N.S.	.778**
		All Levels	.517**	.543**	.438**	N.S.	.434**	.618**
	Rings 1-6	Control	.838**	.724**	.499**	N.S.	.597**	.755**
		150 B.A. Level	.486*	.386*	N.S.	N.S.	N.S.	.726**
		80 B.A. Level	.567**	N.S.	.338*	.458**	N.S.	.781**
		30 B.A. Level	N.S.	N.S.	N.S.	N.S.	N.S.	.846**
		All Levels	.532**	.445**	.249**	N.S.	.395**	.750**

N.S. - Not Significant, * - Significant at the 5% level, ** -Significant at 1% level

TABLE XVII

SIMPLE CORRELATIONS BETWEEN RING WIDTH AND RING NUMBER BY HEIGHT OF DIFFERENT TREATMENT LEVELS. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATION COEFFICIENT, r).

	Ht.	Rings 7-12				Rings 1-6			
		Control	150 BA Level	80 BA Level	30 BA Level	Control	150BA Level	80 BA Level	30 BA Level
Ring Width	Base	N.S.	N.S.	N.S.	N.S.	.413*	.582**	.604**	.888**
	5'	N.S.	N.S.	N.S.	N.S.	.371*	.681**	.687**	.847**
	10'	.359*	N.S.	N.S.	N.S.	.408*	.654**	.741**	.765**
	15'	.418**	N.S.	N.S.	.362*	.363*	.577**	.444**	.701**
	20'	.403*	N.S.	N.S.	N.S.	N.S.	.538**	.518**	.701**
	All	.236**	N.S.	.250**	.169*	.212**	.594**	.520**	.757**

TABLE XVIII

SIMPLE CORRELATIONS BETWEEN CHARACTERISTICS OF THINNED PONDEROSA PINE. NUMERICAL VALUES ARE GIVEN FOR ONLY THOSE VALUES THAT WERE SIGNIFICANT (CORRELATION COEFFICIENT, r). WHERE THE SPACE IS COMPLETELY BLANK NO COMPARISON WAS MADE

	Height	Basal Area Per Acre	Width of Six Ring Segment
Per Cent Live Crown	Base		.463*
	5'		.515**
	10'		.591**
	15'		.479*
	20'		.560*
	All	.514**	.445**
Rings Per Inch	Base	.864**	
	5'	.826**	
	10'	.846**	
	15'	.891**	
	20'	.915**	
	All	.758**	

TABLE XIX

AVERAGE TREE TAPER

Treatment Level	From Pith to Ring Number	Diameter Inside Bark		Taper Inches Per Foot of Ht.
		Base (Inches)	20 feet (Inches)	
	13	4.828	1.144	.184
Control	7	5.248	2.230	.151
	1	5.560	2.882	.134
150	13	3.644	.674	.149
B.A.	7	3.950	1.080	.144
Level	1	4.840	1.600	.162
80	13	4.506	1.528	.149
B.A.	7	5.026	2.108	.146
Level	1	6.764	3.076	.184
30	13	4.330	1.172	.158
B.A.	7	4.770	1.822	.147
Level	1	6.434	2.834	.180

TABLE XX

CHARACTERISTICS OF TREES SAMPLED FROM THE TAYLOR WOODS THINNING PLOTS DUIRING THE SUMMER OF 1969

Thinning Level	Tree No.	Actual Basal Area Per Acre (sq.ft.)	DBHob (in.)	Tree Ht. (ft.)	Height to First Live Limb (ft.)	Live Crown Length (ft.)	Crown Width	
							Base (ft.)	Mid-Point (ft.)
Unthinned	19-1	250	7.88	35.5	15.3	20.2	3.7	7.7
	19-2	360	5.10	31.3	22.0	9.3	3.4	4.0
	20-1	140	8.00	36.5	22.3	14.2	6.2	6.4
	20-2	150	6.40	31.1	15.9	15.2	5.6	6.8
	21-1	170	7.00	33.2	17.3	15.9	6.5	7.2
	21-2	190	4.80	27.2	16.5	10.7	4.3	5.3
	Mean	210	6.53	32.47	18.22	14.25	4.95	6.23
150 Basal Area Level	04-1	100	4.60	25.8	13.2	12.6	4.3	5.5
	04-2	100	6.10	25.3	11.2	14.4	3.3	5.6
	08-1	110	5.90	33.3	18.9	14.4	3.3	6.3
	08-2	100	7.20	33.6	18.0	15.6	4.8	6.5
	10-1	100	6.00	28.0	14.8	13.3	4.9	6.1
	10-2	110	4.40	26.8	13.3	13.6	4.1	4.4
	Mean	103	5.70	28.80	14.90	13.98	4.12	5.73
80 Basal Area Level	06-1	80	5.74	22.8	9.0	14.0	8.8	7.9
	06-2	80	5.71	26.2	12.7	13.7	4.5	6.3
	11-1	80	8.90	36.5	18.6	18.1	6.0	9.0
	11-2	50	8.56	38.1	21.9	16.2	7.2	7.8
	14-1	80	7.60	31.8	14.0	18.2	7.2	8.5
	14-2	90	7.50	35.1	19.2	15.9	6.8	8.4
	Mean	76.7	7.34	31.75	15.90	16.02	6.75	7.98
30 Basal Area Level	07-1	30	7.00	28.5	9.0	19.5	7.3	8.5
	07-2	30	4.50	21.4	11.5	9.9	6.9	6.6
	16-1	30	7.70	36.6	20.8	15.8	8.7	9.0
	16-2	30	9.80	39.3	14.8	24.5	7.7	11.6
	18-1	30	7.80	35.6	14.7	20.9	7.0	10.0
	18-2	30	6.70	31.2	9.8	21.4	5.5	8.0
	Mean	30	7.25	32.10	13.43	18.67	7.18	8.95

TABLE XXI

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 7-12 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts --	3.0	11277919.882	3759306.63	33.699**
Error --	134.0	14948457.382	111555.65	--
Total --	137.0	26226377.265	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
1151.67	886.10	605.99	379.24

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	11.379**	48.045**	87.520**
Bolt 2	--	--	12.660**	37.685**
Bolt 3	--	--	--	7.542**
Bolt 4	--	--	--	--

[1]- F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXII

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 1-6 FROM THE BARK

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	9907872.261	330264.09	21.071**
Error	--	134.0	21002802.765	156737.33	--
Total	--	137.0	30910675.015	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
1318.88	1061.5	783.06	605.29

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	7.608**	32.972**	53.163**
Bolt 2	--	--	8.904**	21.729**
Bolt 3	--	--	--	3.299NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom

NS - Not significant

* - Significant at the 5% level

** - Significant at the 1% level

TABLE XXIII

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 150 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	2210637.126	736879.04	17.559**
Error	--	122.0	5119853.958	41966.02	--
Total		125.0	7330491.082	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
606.69	464.95	302.98	269.77

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	8.618**	39.564**	32.459**
Bolt 2	--	--	11.252**	10.892**
Bolt 3	--	--	--	0.315NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXIV

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 150 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	2787744.159	929248.05	12.738**
Error	--	122.0	8899774.949	72948.97	--
Total	--	125.0	11687519.101	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
815.23	634.03	452.82	468.33

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	8.102**	32.408**	19.796**
Bolt 2	--	--	8.102**	4.517*
Bolt 3	--	--	--	0.040NS
Bolt 4	--	--	--	--

[1] - F Test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXV

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 80 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	5867074.630	1955691.54	23.868**
Error	--	128.0	10488127.382	81938.50	--
Total	--	131.0	16355202.011	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
1002.78	756.17	516.53	472.07

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	13.360**	51.940**	49.500**
Bolt 2	--	--	12.615**	14.184**
Bolt 3	--	--	--	0.347NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXVI

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 80 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	8014540.755	2671513.58	14.401**
Error	--	128.0	23745498.648	185511.71	--
Total	--	131.0	31760039.390	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
1451.74	1086.30	848.31	865.35

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	12.958**	35.331**	26.691**
Bolt 2	--	--	5.496*	3.790NS
Bolt 3	--	--	--	0.023NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not signficant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXVII

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 30 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	4015616.064	1338538.69	10.889**
Error	--	128.0	15734037.445	122922.17	--
Total	--	131.0	19749653.523	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
875.90	687.56	493.81	419.92

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	5.194*	21.378**	24.356**
Bolt 2	--	--	5.497*	8.391**
Bolt 3	--	--	--	0.640NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXVIII

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 30 BASAL AREA LEVEL

Source of Variation		Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	--	3.0	5827265.005	1942421.67	8.075**
Error	--	128.0	30790928.398	240554.13	--
Total	--	131.0	36618193.421	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
1294.34	1009.84	802.30	765.28

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	6.057*	18.116**	16.756**
Bolt 2	--	--	3.223NS	3.580NS
Bolt 3	--	--	--	0.082NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXIX

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	6981516.003	2327172.00	16.743**
Error	584.0	81174661.562	138997.71	--
Total	587.0	88156177.562	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
726.32	418.38	637.11	588.35

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	47.903**	4.379*	10.272**
150 Level	--	--	24.611**	14.594**
80 Level	--	--	--	1.30NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXX

ANALYSIS OF VARIANCE OF ACCUMULATED VOLUME BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	13504896.261	4501632.09	21.163**
Error	584.0	124222858.843	212710.37	--
Total	587.0	137727755.187	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
920.13	598.42	1003.40	934.49

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	34.163**	2.493NS	0.727NS
150 Level	--	--	55.130**	37.282**
80 Level	--	--	--	1.707NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXI

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 7-12 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts (7-12)	3.0	1612.939	537.646	1.35NS
Error (7-12)	134.0	53217.881	397.148	--
Total (7-12)	137.0	54830.820	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
35.43	36.67	37.35	44.59

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXII

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 1-6 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts (1-6)	3.0	1682.301	560.767	1.827NS
Error (1-6)	134.0	41137.494	306.996	--
Total (1-6)	137.0	42819.795	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
27.37	28.39	29.29	36.65

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXIII

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts (7-12)	3.0	794.727	264.909	3.430*
Error (7-12)	122.0	9423.564	77.242	--
Total (7-12)	125.0	10218.292	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
17.84	16.08	15.97	23.44

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	0.725NS	0.817NS	4.866*
Bolt 2	--	--	0.003NS	8.416*
Bolt 3	--	--	--	8.666**
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXIV

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	5070.096	1690.032	2.558NS
Error	122.0	80606.324	660.708	--
Total	125.0	85676.420	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
54.75	44.78	38.18	47.86

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXV

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	1466.652	488.88	2.483NS
Error	128.0	25202.041	196.89	--
Total	131.0	26668.694	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
37.34	31.62	29.75	37.08

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXVI

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	32599.153	10866.38	2.977*
Error	128.0	467272.875	3650.57	--
Total	131.0	499872.028	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
126.93	90.86	89.40	100.75

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	6.418*	6.945**	2.705NS
Bolt 2	--	--	0.010NS	0.386NS
Bolt 3	--	--	--	0.506NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXVII

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	827.813	275.94	1.115NS
Error	128.0	31677.327	247.48	--
Total	131.0	32505.141	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
31.20	31.12	31.27	37.69

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXVIII

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROS PINE, AFTER THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	28478.505	9492.84	2.494NS
Error	128.0	487126.332	3805.67	--
Total	131.0	515604.838	--	--

Bolt Means (Cu. In.)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
121.65	93.48	85.11	89.78

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XXXIX

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	33003.607	11001.20	49.008**
Error	584.0	131096.269	224.48	--
Total	587.0	164099.877	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
38.88	17.88	32.98	32.56

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	137.888**	11.836**	13.342**
150 Level	--	--	72.643**	67.377**
80 Level	--	--	--	0.062NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XL

ANALYSIS OF VARIANCE OF ANNUAL VOLUME BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	521310.017	173770.01	83.171**
Error	584.0	1220161.791	2089.32	--
Total	587.0	1741471.810	--	--

Treatment Means (cu. In.)

Control	150 Level	80 Level	30 Level
32.11	46.34	98.75	96.26

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	6.806**	162.526**	147.706**
150 Level	--	--	93.987**	83.728**
80 Level	--	--	--	0.227NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLI

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 7-12 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	689.054	229.685	4.088**
Error	134.0	7529.027	56.187	--
Total	137.0	8218.081	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
20.35	17.64	16.22	14.09

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	2.365NS	5.476*	11.414**
Bolt 2	--	--	0.644NS	3.656NS
Bolt 3	--	--	--	1.316NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLII

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF UNTHINNED PONDEROSA PINE FOR RINGS 1-6 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	1180.857	393.619	6.754**
Error	134.0	7810.004	58.284	--
Total	137.0	8990.862	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
24.62	21.46	19.55	16.38

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	3.084NS	7.931**	19.056**
Bolt 2	--	--	1.124NS	7.241**
Bolt 3	--	--	--	2.823NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLIII

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	825.247	275.083	6.524**
Error	122.0	5144.167	42.165	--
Total	125.0	5969.415	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
23.34	20.58	18.99	15.42

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	3.246NS	8.095	17.870**
Bolt 2	--	--	1.089NS	7.597**
Bolt 3	--	--	--	3.626NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLIV

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	12.007	4.002	13.750**
Error	122.0	6714.237	55.035	--
Total	125.0	6726.245	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
16.70	16.30	16.00	18.80

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	0.052NS	0.151NS	0.155NS
Bolt 2	--	--	0.026NS	0.043NS
Bolt 3	--	--	--	0.006NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLV

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	773.618	257.87	6.790**
Error	128.0	4861.177	37.98	--
Total	131.0	5634.796	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
21.00	19.24	16.69	14.26

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	1.460NS	8.774**	17.200**
Bolt 2	--	--	3.076NS	9.402**
Bolt 3	--	--	--	2.243NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLVI

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	323.128	101.71	2.538NS
Error	128.0	5337.812	41.70	--
Total	131.0	5660.940	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
17.41	18.85	15.36	14.93

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLVII

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, BEFORE THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	587.143	195.71	3.849*
Error	128.0	6507.802	50.84	--
Total	131.0	7094.946	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
22.13	19.52	17.67	16.39

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	2.423NS	7.067**	9.336**
Bolt 2	--	--	1.214NS	2.766NS
Bolt 3	--	--	--	0.459NS
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLVIII

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN SUCCESSIVE BOLTS OF PONDEROSA PINE, AFTER THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Bolts	3.0	74.643	24.88	2.946NS
Error	128.0	9381.662	73.29	--
Total	131.0	9456.305	--	--

Bolt Means (Per cent)

Bolt 1	Bolt 2	Bolt 3	Bolt 4
19.89	18.37	18.11	18.15

Test Between Means[1]

	Bolt 1	Bolt 2	Bolt 3	Bolt 4
Bolt 1	--	--	--	--
Bolt 2	--	--	--	--
Bolt 3	--	--	--	--
Bolt 4	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE XLIX

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	760.013	234.34	4.984**
Error	584.0	29684.896	50.83	--
Total	587.0	30444.909	--	--

Treatment Means (Per cent)

Control	150 Level	80 Level	30 Level
16.82	19.80	17.33	18.62

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	12.238**	0.381NS	4.777*
150 Level	--	--	8.604**	1.914NS
80 Level	--	--	--	2.527NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE L

ANALYSIS OF VARIANCE OF PER CENT LATEWOOD VOLUME BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	1586.333	528.78	8.867**
Error	584.0	34827.308	59.64	--
Total	587.0	36413.641	--	--

Treatment Means (Per cent)

Control	150 Level	80 Level	30 Level
20.16	16.18	16.29	18.37

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	18.677**	19.171**	4.014*
150 Level	--	--	0.016NS	5.679*
80 Level	--	--	--	5.547*
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LI

ANALYSIS OF VARIANCE OF EARLYWOOD VOLUME BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	24573.078	8191.03	48.746**
Error	584.0	98131.912	168.03	--
Total	587.0	122704.991	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
33.03	14.72	27.60	26.23

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	140.086**	13.453**	20.652**
150 Level	--	--	70.512**	55.336**
80 Level	--	--	--	0.848NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LII

ANALYSIS OF VARIANCE OF EARLYWOOD VOLUME BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	377054.742	125684.91	79.406**
Error	584.0	924366.996	1582.82	--
Total	587.0	1301421.739	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
26.39	39.82	84.15	80.66

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	8.008**	161.206**	139.586**
150 Level	--	--	88.765**	73.988**
80 Level	--	--	--	0.588NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LIII

ANALYSIS OF VARIANCE OF LATEWOOD VOLUME BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	727.414	242.47	22.613**
Error	584.0	6261.976	10.72	--
Total	587.0	6989.390	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
5.83	3.30	5.42	6.32

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	41.873**	1.174NS	1.673NS
150 Level	--	--	30.053**	59.636**
80 Level	--	--	--	5.711*
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LIV

ANALYSIS OF VARIANCE OF LATEWOOD VOLUME BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	11942.553	3980.85	66.861**
Error	584.0	34770.766	59.54	--
Total	587.0	46713.320	--	--

Treatment Means (Cu. In.)

Control	150 Level	80 Level	30 Level
5.74	6.51	14.59	15.58

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	0.714NS	100.626**	122.184**
150 Level	--	--	78.273**	97.028**
80 Level	--	--	--	1.278NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LV

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF UNTHINNED PONDEROSA PINE FOR RINGS 7-12 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.016	0.0041	8.797**
Error	24.0	0.011	0.0005	--
Total	28.0	0.027	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.390	0.357	0.341	0.321	0.335

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	7.196*	15.605**	30.232**	17.868**
5 Feet	--	--	1.607NS	7.929*	2.787NS
10 Feet	--	--	--	2.397NS	0.212NS
15 Feet	--	--	--	--	1.031NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LVI

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF UNTHINNED PONDEROSA PINE FOR RINGS 1-6 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.034	0.0087	14.490**
Error	24.0	0.014	0.0006	--
Total	28.0	0.048	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.414	0.386	0.348	0.328	0.325

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	3.983NS	21.870**	37.278**	36.127**
5 Feet	--	--	7.187*	16.890**	16.873**
10 Feet	--	--	--	2.042NS	2.408NS
15 Feet	--	--	--	--	0.036NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LVII

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE BEFORE THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.021	0.0054	9.317**
Error	23.0	0.013	0.0006	--
Total	27.0	0.035	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.418	0.368	0.344	0.347	0.356

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	12.503**	28.131**	26.140**	15.840**
5 Feet	--	--	3.126NS	2.486NS	0.668NS
10 Feet	--	--	--	0.037NS	0.584NS
15 Feet	--	--	--	--	0.352NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LVIII

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE AFTER THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.027	0.0068	8.704**
Error	23.0	0.018	0.0008	--
Total	27.0	0.045	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.404	0.364	0.342	0.329	0.315

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	6.754**	15.278**	22.604**	25.227**
5 Feet	--	--	1.715NS	4.646*	7.280*
10 Feet	--	--	--	0.715NS	2.331NS
15 Feet	--	--	--	--	0.593NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LVIX

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE BEFORE THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.011	0.0028	2.667NS
Error	24.0	0.024	0.0010	--
Total	28.0	0.036	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.379	0.380	0.349	0.337	0.337

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	--	--	--	--
5 Feet	--	--	--	--	--
10 Feet	--	--	--	--	--
15 Feet	--	--	--	--	--
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LX

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE AFTER THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.020	0.0050	6.974**
Error	24.0	0.017	0.0007	--
Total	28.0	0.037	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.389	0.359	0.343	0.324	0.316

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	3.999NS	8.997**	18.217**	20.827**
5 Feet	--	--	0.999NS	5.146*	7.060*
10 Feet	--	--	--	1.609NS	2.903NS
15 Feet	--	--	--	--	0.244NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXI

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE BEFORE THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.009	0.0024	8.185**
Error	24.0	0.007	0.0003	--
Total	28.0	0.016	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.370	0.358	0.343	0.329	0.319

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	1.601NS	7.940II	16.810**	24.360**
5 Feet	--	--	2.410NS	8.035**	13.900**
10 Feet	--	--	--	1.644NS	5.058*
15 Feet	--	--	--	--	1.053NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXII

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE AFTER THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.014	0.0036	14.497**
Error	24.0	0.005	0.0002	--
Total	28.0	0.020	--	--

Height Means (Sp. Gr.)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.374	0.345	0.328	0.317	0.312

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	9.690**	25.101**	38.531**	41.679**
5 Feet	--	--	3.599NS	9.576**	12.165**
10 Feet	--	--	--	1.433NS	2.819NS
15 Feet	--	--	--	--	0.289NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXIII

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	0.010	0.0037	3.527*
Error	124.0	0.128	0.0010	--
Total	127.0	0.139	--	--

Treatment Means (Sp. Gr.)

Control	150 Level	80 Level	30 Level
0.349	0.367	0.351	0.341

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	4.829*	0.068NS	0.957NS
150 Level	--	--	4.021*	10.186**
80 Level	--	--	--	1.620NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXIV

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	0.016	0.0056	4.007**
Error	124.0	0.173	0.0014	--
Total	127.0	0.190	--	--

Treatment Means (Sp. Gr.)

Control	150 Level	80 Level	30 Level
0.360	0.353	0.339	0.331

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	0.633NS	5.451*	9.847**
150 Level	--	--	2.175NS	5.181*
80 Level	--	--	--	0.742NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXV

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF UNTHINNED PONDEROSA PINE FOR RINGS 7-12 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.110	0.0276	41.461**
Error	169.0	0.112	0.0007	--
Total	173.0	0.223	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.035	0.039	0.049	0.061	0.108

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	0.624NS	5.677*	18.921**	132.820**
5 Feet	--	--	2.537NS	12.675**	116.033**
10 Feet	--	--	--	3.870NS	85.619**
15 Feet	--	--	--	--	54.426**
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXVI

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF UNTHINNED PONDEROSA PINE FOR RINGS 1-6 FROM THE BARK

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.032	0.0081	26.766**
Error	169.0	0.051	0.0003	--
Total	173.0	0.083	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.025	0.029	0.032	0.042	0.064

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	0.468NS	3.224NS	16.418**	84.280**
5 Feet	--	--	1.235NS	11.341**	72.725**
10 Feet	--	--	--	5.091*	55.776**
15 Feet	--	--	--	--	28.271**
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXVII

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE, BEFORE THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.027	0.0070	26.715**
Error	157.0	0.040	0.0003	--
Total	161.0	0.068	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.025	0.026	0.028	0.041	0.067

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	0.123NS	0.441NS	16.886**	81.620**
5 Feet	--	--	0.098NS	14.129**	76.533**
10 Feet	--	--	--	11.868**	72.115**
15 Feet	--	--	--	--	32.254**
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXVIII

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE, AFTER THINNING TO 150 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.007	0.0018	1.755NS
Error	157.0	0.160	0.0010	--
Total	161.0	0.167	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.073	0.065	0.064	0.068	0.086

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	--	--	--	--
5 Feet	--	--	--	--	--
10 Feet	--	--	--	--	--
15 Feet	--	--	--	--	--
20 Feet	--	--	--	--	--

1 - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXIX

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE, BEFORE THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.019	0.0050	12.514**
Error	163.0	0.064	0.0004	--
Total	167.0	0.084	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.043	0.045	0.042	0.062	0.070

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	0.126NS	0.024NS	16.143**	27.454**
5 Feet	--	--	0.259NS	13.416**	24.227**
10 Feet	--	--	--	17.403**	28.915**
15 Feet	--	--	--	--	2.709NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXX

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE AFTER THINNING TO 80 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.046	0.0117	3.790*
Error	163.0	0.505	0.0031	--
Total	167.0	0.552	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.144	0.096	0.106	0.120	0.120

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	13.268**	8.469**	3.244NS	2.617NS
5 Feet	--	--	0.536NS	3.391NS	2.691NS
10 Feet	--	--	--	1.230NS	0.971NS
15 Feet	--	--	--	--	0.000NS
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXXI

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE, BEFORE THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.039	0.0100	27.745**
Error	163.0	0.058	0.0004	--
Total	167.0	0.098	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.036	0.038	0.049	0.063	0.081

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	0.200NS	7.961**	34.492**	79.497**
5 Feet	--	--	5.636*	29.436**	72.520**
10 Feet	--	--	--	9.311**	40.864**
15 Feet	--	--	--	--	13.419**
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXXII

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN SUCCESSIVE HEIGHTS OF PONDEROSA PINE, AFTER THINNING TO 30 BASAL AREA LEVEL

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Heights	4.0	0.022	0.0056	1.485NS
Error	163.0	0.612	0.0038	--
Total	167.0	0.634	--	--

Height Means (Inches)

Base	5 Feet	10 Feet	15 Feet	20 Feet
0.138	0.108	0.109	0.118	0.126

Test Between Means[1]

	Base	5 Feet	10 Feet	15 Feet	20 Feet
Base	--	--	--	--	--
5 Feet	--	--	--	--	--
10 Feet	--	--	--	--	--
15 Feet	--	--	--	--	--
20 Feet	--	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXXIII

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN TREATMENT LEVELS, BEFORE THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	0.064	0.0215	23.186**
Error	728.0	0.675	0.0090	--
Total	731.0	0.740	--	--

Treatment Means (Inches)

Control	150 Level	80 Level	30 Level
0.062	0.036	0.055	0.056

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	63.072**	4.951*	3.672NS
150 Level	--	--	34.041**	36.906**
80 Level	--	--	--	0.086NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5% level
** - Significant at the 1% level

TABLE LXXIV

ANALYSIS OF VARIANCE OF ANNUAL RADIAL INCREMENT BETWEEN TREATMENT LEVELS, AFTER THINNING

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	"F"
Treatments	3.0	0.814	0.0273	124.540**
Error	728.0	1.587	0.0022	--
Total	731.0	2.401	--	--

Treatment Means (Inches)

Control	150 Level	80 Level	30 Level
0.042	0.071	0.118	0.120

Test Between Means[1]

	Control	150 Level	80 Level	30 Level
Control	--	33.985**	251.242**	263.763**
150 Level	--	--	91.446**	99.856**
80 Level	--	--	--	0.269NS
30 Level	--	--	--	--

[1] - F test with single degree of freedom
NS - Not significant
* - Significant at the 5 % level
** - Significant at the 1 % Level